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Modeling and Management of Fire-Induced Pressures in a Model Apartment

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Structural Engineering and Building Technology.

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Abstract

Fire developing in a mechanically ventilated airtight compartment can induce high pressure. The significance of this arisen pressure and the risks involved with it were explored in this study. Previously, no effort has been made to study the impact of realistic fire growth rates over compartment pressures in a residential setting. This research is based on a fire development scenario exhibiting a model apartment in a multi-story residential building. This thesis study documents the behavior of fire-induced compartment pressure relative to involved variables. This thesis also devises an alternate method of computing fire-induced pressures in airtight compartments. Finally, this thesis proposes solutions for the management of the encountered overpressure under apartment fire scenarios.

Fire-induced pressure as a function of fire growth rate, envelope airtightness, and damper configuration was studied using Fire Dynamics Simulator (FDS). Pressure behavior, peak pressure values, and variable trends were the focus of this study. Results suggest that pressure increases with faster fire growth rate and overall airtightness of the compartment. In addition, the sensitivity of pressure to a parameter value seemed to increase when moving towards a faster fire growth or increased overall air-tightness of the compartment. It was found that the pressure rise can risk the occupants' escape from the inward-opening door for medium and faster fire growth rates. Overpressure can cause structural damage to a near-zero envelope with a fast or ultra-fast fire growth rate.

An analytical model was developed from the basic assumption of an ideal gas as an alternate way to capture the pressure rise related to compartment fire scenarios. The model was validated with the known FOA and AALTO experiments' simulation and experimental data. In comparison to FDS results, the analytical model captured the pressure behavior in an apartment fire scenario with reasonable accuracy. The positive peak pressures were captured with an average difference of 5%. The model was found reliable in all configurations of input variables.

In order to deal with the overpressures encountered, recommendations were made for additional leakage areas required to diminish the overpressure under the threshold safety limits of occupant safety and structural integrity. The findings were also verified using the FDS simulations. Finally, for managing the pressure in practical scenarios, the pressure threshold limits were converted into their equivalent bulk leakage area limits for different ventilation configurations.

Keywords Apartment fire, Fire growth rate, Envelope airtightness, Damper configuration, Fire-induced pressure, Analytical model, Pressure management, Occupant safety, Structural Integrity.

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Preface

By the grace of Allah, this Master's thesis work concludes an amazing research journey, spanning June – November 2016, at Aalto University. This work was done within the scope of "Paineenhallinta huoneistopaloissa" (PAHAHUPA) research project funded by the Finnish Fire Protection Fund (PSR), Ministry of Environment, Hagab AB, and the Criminal Sactions Agency of Finland. Research partners include Aalto University, Stravent Oy, VTT Technical Research Center of Finland Ltd., Palotekninen Insinööritoimisto, Markku Kauriala Oy, and Southwest Finland Emergency Services.

I would like to acknowledge Mr. Topi Sikanen of VTT, who first developed the apartment fire scenario as a case study within the scope of PAHAHUPA-project. This thesis uses his case study as a basis. The input files for the simulations in this thesis are edited versions of the input files created by Mr. Topi Sikanen.

I would like to express my gratitude to my thesis supervisor Prof. Simo Hostikka for believing in me, even when I had no background of fire safety studies. He has been a truly supportive mentor, an awesome teacher and an encouraging figure to me. Prof. Simo has an inspiring touch, which pushed me to go the extra mile. I will also like to acknowledge the unshakeable assistance of my advisor Mr. Rahul Kallada Janardhan, in terms of mentoring, teaching, guidance, support and providing me with a friendly work environment. I am indebted to both of them for their constant encouragement and a vast base of knowledge that I acquired from them.

Finally, I would like to thank my parents for their support and dedicate this research to my father who has been my ideal since childhood. I would also like to thank my entire family and friends who supported me throughout my studies. Especially I would like to thank my friend Mr. Hassaan Mohsin for his support through my sickness, as without his help I would not be able to achieve what I did.

List of Symbols

Q	Heat Release Rate (HRR)
Q_o	Reference Heat Release Rate, normally chosen to be 1 MW
t	Time [s]
t_g	Time taken by a fire growth rate to reach reference HRR
V_1	Volume at start of time step [m^3]
V_2	Volume at end of time step [m^3]
T_1	Temperature at start of time step [K]
T_2	Temperature at end of time step [K]
$\Delta P = P_{\text{inside}} - P_{\text{ambient}}$	Pressure difference across an orifice, [Pa]
$\dot{V}$	Volumetric flow rate due to pressure difference, [m^3s^{-1}]
A	Area of opening/leak area, [m^2]
ρ	Density of hot gasses in the room, [kg/m^3]
C_d	Discharge coefficient
P	Pressure [Pa]
n	Number of Moles [moles]
R	Ideal Gas Constant [m^3 Pa K^{-1} mol^{-1}]
A_o	Leakage equivalent orifice area, [m^2]
q_{50}	Air permeability rate at a 50 Pa pressure difference [$m^3m^2h^{-1}$]
S	Surface area of compartment [m^2]
A_L	Leakage area calculated based on air permeability rates [m^2]
ρ_∞	Ambient density, [kg/m^3]
n_{50}	Air change rate at 50 Pa pressure difference [h^{-1}]
A_{fuel}	Fuel surface area [m^2]

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1. Introduction

Early fire growth in a room naturally raises the gas temperature, which leads to an increase in the air volume due to the expansion of hot gasses. If the room is closed except for small cracks around closed doors and windows, the increase of temperature creates a pressure rise inside the room. In recent years, fire-induced pressure has emerged as a potential threat to modern fire safety due to its ability to trap inhabitants inside burning enclosures and cause structural damage.

Previously, fire-induced pressure has been quantified and studied using experimental as well as simulation studies. Swedish Defence Research Establishment (FOA) [1], [2] first quantified pressure rise due to a liquid pool fire burning in an enclosure with a small opening to the ambient. In the next phase of the study, they studied the influence of pressure rise due to fire growth in a closed room on the smoke spread via ventilation ducts to adjacent spaces. They found that the spread of smoke and hot gasses to adjacent compartments during a fire depends on fire growth rate, the area of the leakage paths and the layout of the ventilation system.

Experiments within the OECD PRISME fire research program [3] produced a large database for the smoke and heat propagation mechanisms in a multi-compartment airtight enclosure under a liquid pool fire. The test results provided evidence of pressure variations during the fire scenarios in a confined and forced ventilated enclosure. The pressure was found to be a function of fire power, thermal properties of the enclosure and flow through the ventilation network. The overpressure recorded was high enough to create a reverse flow through the ventilation system. Using the PRISME program data, Prétrel et al. [4], [5] found enclosure airtightness to have a direct impact on pressure rise using experimental and theoretical analysis. Fourneau et al. [6] identified the increased fire pressure as one of the consequences of the better energy efficiency, concluding that the high pressure can lead to a reverse flow in the supply ventilation system. Fire scenarios are also changing with time, in terms of design layouts for houses, fire loads, and new construction, as well as, furnishing materials, which burn faster [7].

Janardhan [8] and Janardhan and Hostikka [9] performed an experimental and simulation-based study of pressure effects in apartment fires. The study was based on a series of thirteen experiments, known as “Aalto Experiments”, performed in an old apartment building, constructed in 1970’s in Kurikka, Finland. The study involved different operating conditions created by varying the fuel type and duct configurations. The study investigated the development of gas pressures and its accompanied flows in the compartment. The overpressures encountered varied with a change in the operating configurations. The overpressures were high enough to revert the flows in the ventilation system, prevent escape through inwards opening doors and cause structural damage. The pressure data was reproduced with a reasonable accuracy using Fire Dynamics Simulator (FDS).

Using the capability of FDS to regenerate the experimental data reasonably, VTT Technical Research Center of Finland Ltd. performed a set of simulations using the Heat Release Rate (HRR) curve of Aalto experiments (PUR mattress fire curve) for a model apartment. The influence of the envelope air-tightness on the fire-induced pressures and smoke spreading in the ventilation network was the focus of this case study. The pressure was found to be sensitive to airtightness of envelope and ventilation system. The recorded fire-induced pressures were high enough to exceed the thresholds of occupant safety and structural integrity. Fan state had no influence on pressure values, but had a huge impact on smoke distribution to adjacent spaces, along with damper configuration.[1]

1.1. Motivation

Combining the overpressure risks with the contemporary trends in construction requirements and practices, which are rapidly moving towards more airtight building envelopes, we can expect the pressure related risks to become more significant unless the preventive measures are devised. Previous studies like FOA [1], [2] and PRISME [3] do not represent residential fire scenarios. Kurikka experiments [8], [9] used fire growth rates falling under the category of ultra-fast fires, which are unlikely in a residential setting. Fire-induced pressures shall be further examined using more realistic fire growth rates in a residential environment.

Carrying out FDS simulations for every situation is computationally expensive, time-consuming and requires a skilled hand. The application of analytical approaches to capture and study pressure rise under compartment fire scenarios is missing from the literature. Analytical approaches shall be explored to provide easier and faster ways to study fire-induced pressures in confined compartments.

Literature also lacks in suggesting ways to deal with the fire-induced overpressure. The contemporary situation demands that overpressures shall be limited to ensure the safety of inhabitants as well as the structures themselves.

1.2. Research Objectives and Approach

This thesis contains three distinguishable objectives:

- The first objective of this thesis is to study the fire-induced pressure as a function of fire growth rate, building envelope's permeability, and damper configuration.
- The second objective is to devise an analytical model to predict the pressure rise in a fire compartment, based upon the average temperature rise of enclosures gas volume and its associated volume flow.
- The final objective of this thesis is to manage the pressure raised due to fire, by allowing dissipation through a designed additional leakage area, which activates in case of fire only. This objective also encompassed the sensitivity study of peak pressure relative to the envelopes bulk leakage area.

Fire Dynamics Simulator (FDS) is used as the tool to study fire-induced pressures. The analytical model, developed as an objective of this thesis, is used to recreate the simulation results and devise pressure management solutions.

[1] Based on private communication with Mr. Topi Sikanen of VTT within the scope of PAHAHUPA-project.

1.3. Scope and Limitations

The scope of this thesis work is to study the fire-induced pressure in only residential conditions using anticipated fire growth rates. The scope includes derivation of an analytical model, which can be used to compute fire-induced pressures in compartment fire scenarios.

Simulation geometry includes simplifications with respect to a realistic building geometry. The focus is limited to the pressure in fire apartment only. Smoke behavior or smoke spread to surrounding spaces and structural behavior relative to fire-induced pressures are not studied. The study does not account for pressure drops associated with fire extinction. The analytical model is derived using the basic assumptions of ideal gas law. Pressure management studies are only done for one fire growth rate and one envelope type.

1.4. Thesis Structure

This thesis is divided into six chapters. Chapter 2 introduces and discusses the important variables in fire-induced pressure studies. Chapter 3 presents the derivation of the analytical model, inputs required for the application of model and validation of said model using known experimental data. Chapter 4 describes the methodology used for studying fire-induced pressures in apartment conditions and overpressure management. Chapter 5 reports and evaluates findings of this thesis. Chapter 6 concludes this thesis.

2. Background

Literature suggests that fire-induced pressure is dependent on fire type and available leakage paths that connect inside of compartment to the ambient. Fire type relevant for residential fire scenario is compartment fire. The available leakage paths in residential environment depend upon the airtightness of the building envelope and the ventilation network present.

2.1. Compartment Fire

The process of compartment fire development can be divided into periods or stages. Based on the contemporary literature, a typical compartment fire can be divided into four distinct time periods, encompassing the complete fire growth process, as shown in Figure 1 [10].

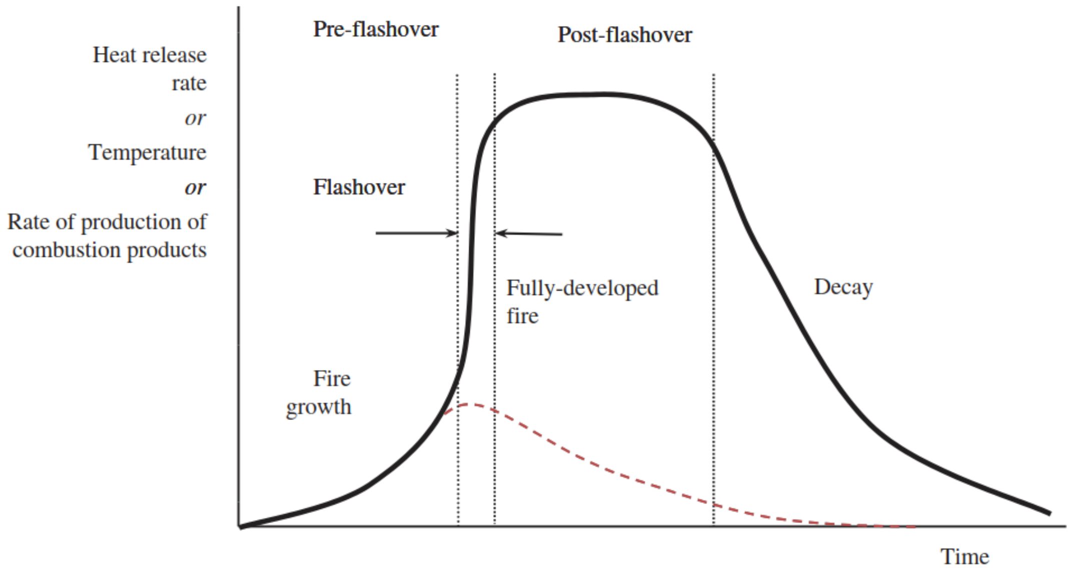

Figure 1: Phases of a typical compartment fire. [10]

Compartment fires can be segregated as either *fuel-controlled* or *ventilation-controlled* fire. Provided sufficient oxygen is available for combustion, the fire growth is solely dependent on the flammability and configuration of the fuel, and hence, is categorized as fuel-controlled. A fire is ventilation-controlled when there is not enough oxygen available to combust all the fuel available inside the enclosure, and the combustion is dependent on the airflow through the compartment openings. [10]

Traditionally, standard design fires with predefined fire growth rates are used for compartment fire studies. The most frequently used design fires are the t^2-fire growth rate curves, where the heat release rate (HRR) is described as:

$$Q = Q_0\left(\frac{t}{t_g}\right)^2 \qquad (1)$$

where Q_0 is normally chosen to be 1 MW. The recommendations for t_g are 600, 300, 150, and 75 seconds for slow, medium, fast, and ultra-fast fires respectively [11].

2.2. Airtightness of Building Envelopes

The pursuit of low carbon footprint and energy efficient buildings is guiding the construction industry towards reducing the leakage through the building envelope and the transition has been from the traditional envelopes to modern and quite recently to near-zero leak rate envelopes. In the later part of 20th century, we see an increased focus towards improving the airtightness of building envelopes, which resulted in the conception and maturing of energy efficient buildings by the end of the century [12]. The Association for Environment Conscious Building (AECB) [13], with support from the Carbon Trust, has launched a Carbon Lite program aimed at improving the 'carbon literacy' of the construction industry. It contains three standards based on maximum air permeability values. The Silver Standard allows a maximum air permeability of 3 m^3/hm^2 against a pressure of 50 Pa. The middle standard is the PassivHaus standard, which permits a maximum air permeability not exceeding 0.6 air changes per hour at 50 Pa. The Gold Standard attains the performance levels required by the PassivHaus standard, with the addition of renewable energy to reduce fossil fuel use for water heating, lighting, appliances, and ventilation. It qualifies for a maximum air permeability of 0.75 m^3/hm^2 at 50 Pa. Wei Pan [14] identifies Super E standard used in Canada, specifying a maximum air permeability of 1.5 m^3/hm^2 at 50 Pa.

Air-tightness is reported in many units, some of the most frequently used are m^3/m^2h, m^3/s and air change rate per hour (ACH). Authors in [15] found huge variations in air permeability values for the existing buildings in Finland. For old small residential houses, the averaged air permeability (q_{50}) value was found to be 2.6 m^3/m^2h for stone houses, 3.9 m^3/m^2h for wooden houses and 5.7 m^3/m^2h for log houses. For the new small houses built during 2012-2015, averaged air permeability (q_{50}) value was found to be 1.17 m^3/m^2h for stone houses, 1.19 m^3/m^2h for wooden houses and 1.9 m^3/m^2h for log houses. Average values of air change rates are affected by factors like construction methodology and insulation materials, for example, polyurethane insulation in timber-framed houses, seam insulation material in log houses and ceiling structure in heavyweight buildings, among other factors. In 2015, another study in [16] found the averaged air permeability (q_{50}) value to be 1.4 m^3/m^2h for new small residential buildings and 3.7 m^3/m^2h for the existing small residential buildings.

2.3. Ventilation Systems

Ventilation systems can be classified as *natural, mechanical* or *hybrid* (a mixture of the two). *Natural ventilation* is the process of supplying and removing air through an indoor space by employing buoyancy and without the use of a fan or other mechanical system. Therefore, the ventilation rates in natural ventilation depend on the size and distribution of the openings in the building envelope and on the magnitude of the driving forces such as thermal buoyancy and wind. *Mechanical ventilation* is based on the requirement that a specified ventilation rate is maintained in all weather conditions. When ventilation is provided by a mechanical supply and exhaust system, the building envelope can be made airtight, and energy losses due to infiltration and exfiltration can, therefore, be reduced. *Hybrid ventilation* consists of an auxiliary low-energy extract fan located in natural ventilation extraction duct, to improve the efficiency of natural ventilation and to increase the range over which low-energy ventilation methods can be applied. In the modern day constructions, mechanical ventilation systems dominate, as per the requirements of energy efficiency, space management and high-rise structures [17].

For the fire-induced pressure within a mechanically ventilated closed enclosure space, the most relevant ventilation system components are dampers and fans. Compartmenting the building with fire-rated separations like fire walls, fire barriers, fire partitions, smoke barriers, and smoke partitions is a critical feature of a passive fire protection system. When the ductwork of heating, ventilation or air conditioning (HVAC) system penetrates these walls or partitions, the ratings of the fire-rated separations is ensured by the use of fire dampers, smoke dampers, or combination fire/smoke dampers. A fire damper closes once the temperature of flowing gas reaches a high enough level to melt a fusible link. A smoke damper closes upon the detection of smoke. The best agreed upon method of compartmentalization is using the combination fire/smoke damper [18]. Fans are typically found in mechanical ventilation systems for both inlet and exhaust networks, and play an important role in smoke spreading from the fire compartment to the neighboring enclosures.

3. Analytical Model for Fire-Induced Pressures

3.1. Basis of Model

An enclosure gas volume expands upon heating. If the gas volume is heated from a temperature T_1 [K] to a higher temperature T_2 [K] during a time period Δt under a constant pressure, the increased gas volume V (m^3) is given by the following equation:

$$V_2 = \left(\frac{T_2}{T_1} - 1\right) * V_1 \ [\mathrm{m}^3] \tag{2}$$

where subscripts 1 and 2 indicate the start and end of the time step.

If the enclosure volume is constant, temperature rise accompanies a pressure increase inside the enclosure. This increased pressure induces a volume flow through the available leak paths. Flow through an orifice equation can estimate the induced volume flow ($\dot{V}$), given as under:

$$\dot{V} = C_\mathrm{d} A \sqrt{\frac{2\Delta P}{\rho}} \ [\frac{\mathrm{m}^3}{\mathrm{s}}] \tag{3}$$

where

$\Delta P = P_{\mathrm{inside}} - P_{\mathrm{ambient}}$: Pressure difference across the orifice, [Pa]

$\dot{V}$: Volumetric flow rate due to pressure difference, [m^3/s]

A: Area of opening/leak area, [m^2]

ρ: Density of enclosure gas, [kgm^{-3}]

C_d: Discharge coefficient.

3.2. Analytical Model Derivation

3.2.1. Fire Flow Method

Fire burning in a constant volume compartment generates a volume flow across its envelope. A relation derived from the ideal gas law can express this volume flow. Assuming a steady state flow across the envelope, Ideal gas law ($PV/T = nR$) can be written as:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \tag{4}$$

where P represents the pressure and subscripts 1 and 2 indicate the start and end of time steps.

From (4) the gas pressure at the end of the time step is:

$$P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} \tag{5}$$

The total volume change is the original compartment volume plus the volume of the accompanying flow through the leakage, given by (6),

$$V_2 = V_1 + \dot{V}\Delta t \tag{6}$$

where the gas volume ($\dot{V}\Delta t$) exiting the chamber is not in the same pressure anymore.

By transforming leakage area into its equivalent orifice area, the total volumetric flow can then be calculated using (3). Substituting (3) in (6), we get:

$$V_2 = V_1 + (C_\mathrm{d}A\sqrt{\frac{2(P_2 - P_\mathrm{amb})}{\rho}})\Delta t \tag{7}$$

Using (7) in (5), we get a relation for the gas pressure at the end of time step due to enclosure fire:

$$P_2 = \frac{P_1 V_1 T_2}{T_1(V_1 + (C_\mathrm{d}A\sqrt{\frac{2(P_2 - P_\mathrm{amb})}{\rho}})\Delta t)} \tag{8}$$

Rearranging (8), gives:

$$P_2\left(V_1 + \left(C_\mathrm{d}A\sqrt{\frac{2(P_2 - P_\mathrm{amb})}{\rho}}\right)\Delta t\right) = P_1\frac{T_2}{T_1}V_1 \tag{9}$$

Assuming a constant density throughout, equation constants in (9) can be combined as $C_a = C_d A/\sqrt{\rho}$ and further into $C = C_a\Delta t$, provided time steps are equal. Equation (9) can now be rewritten as:

$$P_2\left(V_1 + C\sqrt{2(P_2 - P_\mathrm{amb})}\right) = P_1\frac{T_2}{T_1}V_1 \tag{10}$$

The final implicit relation for calculating the pressure rise in a compartment fire scenario is:

$$P_2\left(V_1 + C\sqrt{2(P_2 - P_\mathrm{amb})}\right) - P_1\frac{T_2}{T_1}V_1 = 0 \tag{11}$$

3.2.2. Mass Conservation Method

If the equation constants are combined as $C_a = C_d A/\sqrt{\rho}$, flow through an orifice relation, given as (3) above, can be redefined as

$$\dot{V} = C_d A\sqrt{\frac{2\Delta P}{\rho}} = C_a\sqrt{2\Delta P} \tag{12}$$

Conservation of mass requires that mass flow through the leak paths shall be equal to the change of mass inside the chamber. The volume stays constant due to the chamber being tightly sealed, hence, only the density change term stays as a variable, as shown in (13).

$$-\dot{V}\rho = \frac{d}{dt}(V\rho) = V\frac{d\rho}{dt} + \rho\underbrace{\frac{dV}{dt}}_{0} = V\frac{d\rho}{dt} \tag{13}$$

The ideal gas law can be written in the form of $\rho = MP/RT$, where M is the mass of the gas volume. Using this in (13) yields,

$$-\dot{V}\left(\frac{MP}{RT}\right) = V\frac{d}{dt}\left(\frac{MP}{RT}\right) \tag{14}$$

Canceling the common terms yields:

$$-\dot{V}\left(\frac{P}{T}\right) = V\frac{d}{dt}\left(\frac{P}{T}\right) \tag{15}$$

$$\Longrightarrow \qquad -\dot{V}\left(\frac{P}{T}\right) = V\left[\frac{1}{T}\frac{dP}{dt} + P\frac{d}{dt}\left(\frac{1}{T}\right)\right] \tag{16}$$

Multiplying equation (16) by *'T'*

$$-\dot{V}P = V\frac{dP}{dt} + PVT\frac{d}{dt}\left(\frac{1}{T}\right) \tag{17}$$

Rearranging (17),

$$V\frac{dP}{dt} = -\dot{V}P - PVT\frac{d}{dt}\left(\frac{1}{T}\right)$$

$$\frac{dP}{dt} = -\frac{\dot{V}}{V}P - PT\frac{d}{dt}\left(\frac{1}{T}\right)$$

$$\frac{dP}{dt} = \left[-\frac{\dot{V}}{V} - T\frac{d}{dt}\left(\frac{1}{T}\right)\right]P$$

$$\frac{dP}{P} = -\frac{1}{V}\dot{V}dt - Td\left(\frac{1}{T}\right) \tag{18}$$

For ease of derivation, a dummy variable ($\hat{T} = 1/T$) in introduced in (18) yielding:

$$\frac{dP}{P} = -\frac{1}{V}\dot{V}dt - \frac{d\hat{T}}{\hat{T}} \tag{19}$$

Integrating equation (19) over a time interval t ϵ [t_1, t_2]

$$\int_{P_1}^{P_2}\frac{dP}{P} = -\frac{1}{V}\int_{t_1}^{t_2}\dot{V}dt - \int_{T_1}^{T_2}\frac{d\hat{T}}{\hat{T}}$$

$$|\ln(p)|_{P_1}^{P_2} = -\frac{1}{V}\int_{t_1}^{t_2}\dot{V}dt - \ln\left(\frac{\hat{T}_2}{\hat{T}_1}\right)$$

Simplifying,

$$\ln\left(\frac{P_2}{P_1}\right) = -\frac{1}{V}\int_{t_1}^{t_2}\dot{V}dt - \ln\left(\frac{T_1}{T_2}\right)$$

If $\dot{V}$ is assumed to be constant in a time step t ϵ [t_1, t_2], the above equation can be written as

$$\ln(\frac{P_2}{P_1}) = -\frac{\dot{V}\Delta t}{V} - \ln(\frac{T_1}{T_2})$$

Taking the antilog of the above equation,

$$\frac{P_2}{P_1} = e^{-\frac{\dot{V}\Delta t}{V}} * e^{-\ln(\frac{T_1}{T_2})}$$

$$\frac{P_2}{P_1} = e^{-\frac{\dot{V}\Delta t}{V}} * (\frac{T_1}{T_2})^{-1} = e^{-\frac{\dot{V}\Delta t}{V}} * \frac{T_2}{T_1}$$

$$P_2 = P_1 * e^{-\frac{\dot{V}\Delta t}{V}} * \frac{T_2}{T_1}$$

Substituting (12) in the above equation gives an implicit relation for estimating pressure rise under compartment fire

$$P_2 - P_1 * e^{-\frac{(C\sqrt{2\Delta P})}{V}} * \frac{T_2}{T_1} = 0 \tag{20}$$

3.2.3. Relation between the Two Equations

Expanding the exponential terms of the mass conservation equation (20),

$$P_2 - P_1 * e^{-\frac{(C\sqrt{2\Delta P})}{V}} * \frac{T_2}{T_1} = 0$$

using the first two terms of Taylor series as $e^{-((C\sqrt{2\Delta P})/V)} \approx 1 - ((C\sqrt{2\Delta P})/V)$ gives an approximate formula

$$P_2 - P_1 * (1 - \frac{(C\sqrt{2\Delta P})}{V}) * \frac{T_2}{T_1} = 0$$

Simplifying and multiplying with '*V*'

$$P_2 V - P_1 \frac{T_2}{T_1} V + P_1 C\sqrt{2\Delta P}\frac{T_2}{T_1} = 0$$

Taking P_2 common,

$$P_2(V + \frac{P_1}{P_2} C\sqrt{2\Delta P}\frac{T_2}{T_1}) - P_1 \frac{T_2}{T_1} V = 0 \tag{21}$$

In real life scenarios, enclosure pressurization makes the mass inside compartment variable. If the pressure at the end of the time step (P_2) is assumed to follow the Ideal gas law, meaning the number of moles stay constant during the steady volume flow across the envelope, we can write:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \tag{22}$$

Substituting (22) in (21) reproduces fire flow equation (11),

$$P_2 * \left(V + C\sqrt{2(P_2 - P_{amb})}\right) - P_1 * \frac{T_2}{T_1} * V = 0$$

This proves that fire flow method follows mass conservation method provided an exponential function approximates the pressure rise and pressure rise follows the Ideal Gas law (assumption (22) holds). Therefore, either of the two developed relations can be used to estimate the pressure rise due to fire growth in an enclosure.

For the validation of equivalence between fire flow equation and mass flow equation, FOA series 1, test 1 case was plotted for both equations and the comparison plot obtained is shown in Figure 2. Both equations predict the same pressure rise behavior and peak values, which validates the assumptions of pressure following Ideal Gas Law and an exponential relation holding for overpressure. Hence, any of the two derived equations are equally compatible for pressure rise estimations under compartment fires.

As the both equations are implicit for P_2, MATLAB iterative solver was used to determine the value of pressure at the end of each time step (P_2) for every interval. This pressure served then, as the initial pressure (P_1) for the next time step. It was assumed that at the start of the study that pressure inside the enclosure equals the outside ambient pressure (P_{amb} = 101325.17 Pa). A model MATLAB script used for these iterations is given in Appendix 1: Analytical Model Matlab function.

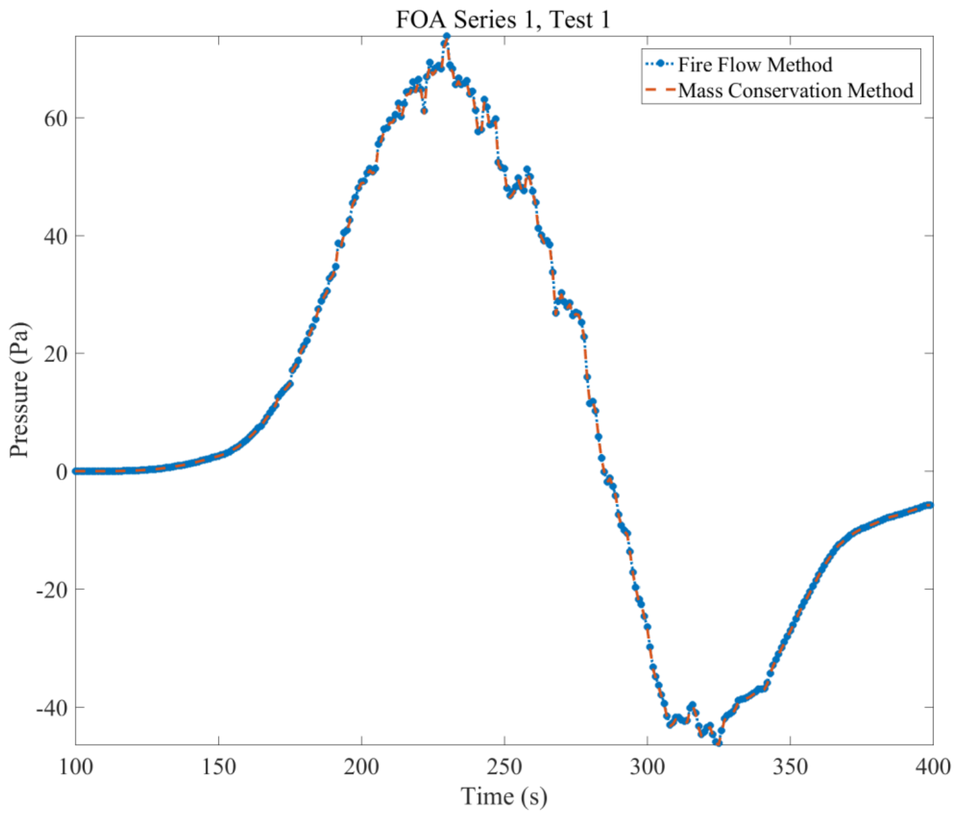

Figure 2: Equivalence between fire flow method and mass conservation method

3.3. Model Inputs

The input data required for the analytical model includes:

- Average enclosure volume gas temperature.
- The volume of the enclosure, obtained from the geometry of the chamber.
- Area of the vent, or leakage area from which equivalent orifice area can be calculated.
- The density of enclosure air, given by the relation 353/T_2, to account for the change of density w.r.t. the temperature at each time step.
- The discharge coefficient (C_d) can range in the limits of 0.5-1 depending on the leakage type. In this study, a discharge coefficient of 0.6 was used.

  Variable discharge coefficients were used as inputs in the analytical model for the comparative study relative to simulation results. This was done because FDS default discharge coefficient is 1, but it changes when the 'LOSS' term changes. 'LOSS' is specified for the ducts to control the volume flows through the network. The guiding relation between 'LOSS' and discharge coefficient is [19]:

  $$LOSS = \left(\frac{1}{C_d}\right)^2 \tag{23}$$

- The time step was used as given by FDS simulations data, to keep the comparison plots in same limits. The time step used was 1 s.

3.4. Model Validation

The analytical model was validated by reproducing the pressure plots for the FOA series 1 experiments [1] and AALTO Experiments [8]. Filtering over 25 seconds was applied to reduce the simulation noise (data spikes) from FDS as well as analytical model pressure data curves. In addition, FDS pressures were corrected for a bias factor of 0.87 calculated in accordance with the guidelines provided in [19]. Experimental pressure data is used in its original form.

3.4.1. FOA Series 1

FOA series 1 had three experimental full-scale tests, one with each fire growth rate. The fuel was heptane burnt in square steel pans. The tests were performed in a sealed room except for a vertical, circular opening of diameter 0.20 m to the outside. The floor area was 4.0 m x 5.5 m and the ceiling height was 2.6 meters, which gave a total enclosure volume of V = 4.0 x 5.5 x 2.6 = 57.2 m^3 [1]. The leakage area was taken as the area of the opening calculated as:

$$A_{openning} = \frac{\pi}{4} d^2 = \frac{3.14}{4} 0.2^2 = 0.0314\ m^2$$

The compartment average gas temperatures were determined using FDS simulations. A discharge coefficient C_d = 1 was used for all the tests as no LOSS term for outlet duct was specified in the simulation file.

The comparison plots are given in Figure 3, for all the three tests in series 1 of FOA experiments. The pressure behavior was captured quite well by the analytical model. The analytical model underestimates the FDS simulated and experimental positive pressure peaks. For negative pressure peaks, analytical model approximates better than FDS, as can be seen in Figure 3. Pressure drop is not discussed in detail here, as it is not a focus of this thesis study.

Compared to the experimental pressure data, analytical model underestimates positive peak pressures by 47%, 22%, and 58% for test 1, 2, and 3 respectively. FDS on the other hand, captured positive peak pressures for test 1, 2, and 3 by a relative difference of 0.29%, 14%, and 14% respectively. Compared to FDS peak pressures, analytical model underestimates positive pressure peaks by 46%, 40%, and 39% for test 1, 2, and 3 respectively. Hence, FDS simulated positive pressure peaks provide a better approximation for experimental peaks for FOA series experiments, as compared to the analytical model.

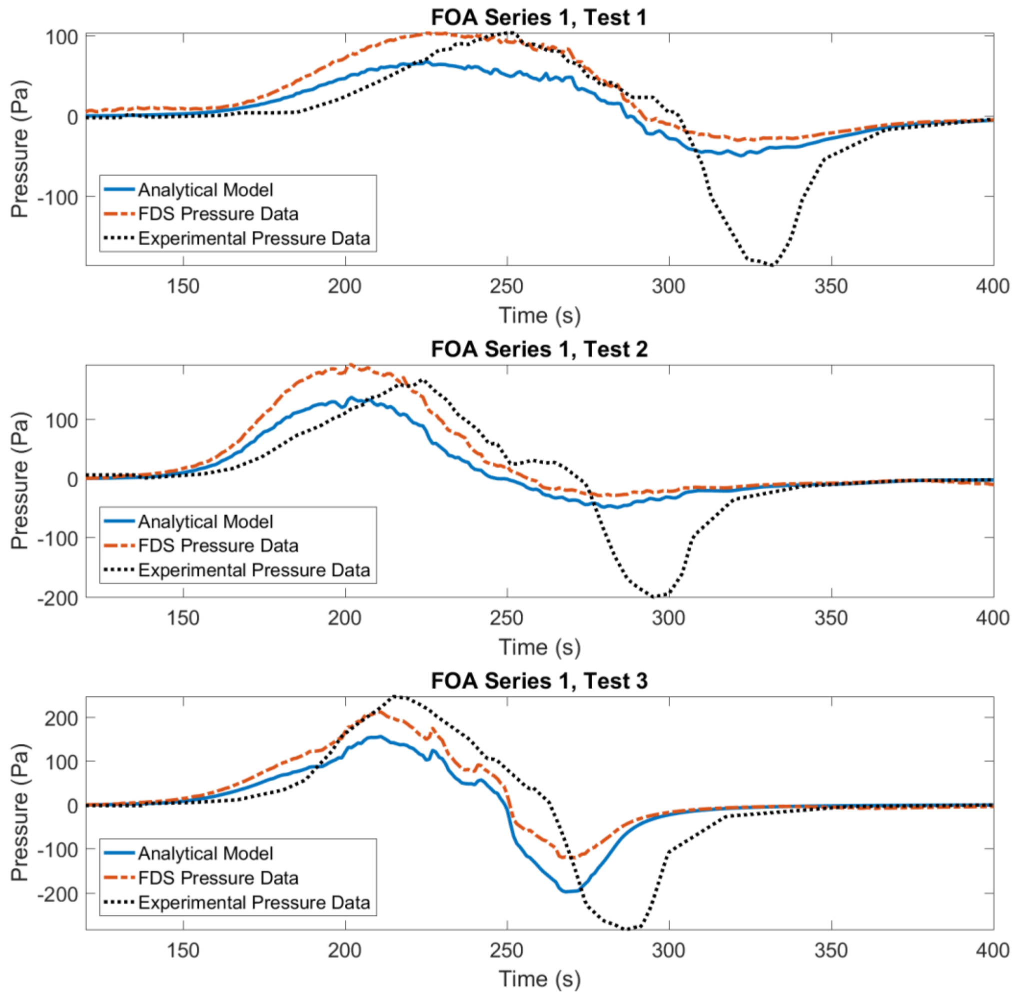

Figure 3: Validation plots for FOA series

3.4.2. Kurikka Experiments

Thirteen full-scale compartment fire tests were conducted in an apartment building, constructed in the 1970's, in Kurikka, Finland. Two types of fuels were used for this experiment, liquid fuel was used in first 10 tests and solid fuel was used in the last three tests. The height of the apartment was 2.57 m, floor area was 58.56 m^2 and the envelope area was 164.9 m^2 (leakage associated area of the apartment), which, included the floor and the ceiling areas as well. The total enclosure air volume was

$$V = floor\ area * height = \ 58.56m^2 * 2.57m = 150.49\ \mathrm{m}^3.$$

The apartment ventilation was a combination of Mechanical exhaust ventilation system and natural ventilation. The apartment had three main exhaust ducts in the bathroom, closet, and the kitchen. The kitchen exhaust remained closed in all tests, leaving behind only two operating ducts one in the bathroom and the other in the closet. The two ducts connected apartment inside to the ambient through an exterior vertical exhaust. The exhaust duct diameters were assumed 0.125 m, but the actual channel diameters throughout the building were not known.

The experiments were done under different ventilation conditions to study the effect of the ventilation on the pressure rise in the apartment. The three configurations of the ventilation ducts used in these experiments are given as follows:

- **Open:** Ducts completely open, unhindered flow of exhaust gasses.
- **Normal:** Ducts with louvers installed, partially free flow of exhaust gasses. (assumed as 50% duct area is blocked)
- **Closed**: Ducts completely sealed to prevent any flow of exhaust gasses.

A discharge coefficient (C_d) of 0.6 and air density at 20°C, which is 1.204 kg/m^3, were used for equivalent orifice leakage area calculation. The leakage flow was calculated to be 121.1 L/s (0.121 m^3/s) against a pressure difference (ΔP) of 50 Pa [8]. Leakage equivalent area of the orifice was calculated from leakage measurements using flow through an orifice equation, (3) given above, as follows:

$$A_o = \frac{0.121\frac{m^3}{s}}{0.6 * \sqrt{\frac{2 * 50Pa}{1.204\frac{kg}{m^3}}}} = 0.02213\ m^2$$

For the validation of the analytical model, tests 3, 5, and 8 were simulated with FDS to get the comparison pressures and average gas temperatures inside the enclosure. These three tests depict every ventilation configuration used in the study. FDS incorporates discharge coefficient on the basis of LOSS term specified for the ducts. Three different discharge coefficients were used as an input for the analytical model depicting the envelope bulk leakage, inflow ducts, and outflow ducts respectively. For envelope there is no LOSS term specified, therefore, the discharge coefficient was taken as 1. For the inflow and outflow ducts LOSS term varied, which changed the modeled discharge coefficients accordingly, as per equation (23). The used coefficients were $C_{d\ (envelope)} = 1$, $C_{d\ (inflow\ ducts)} = 0.1195$, and $C_{d\ (outflow\ ducts)} = 0.1622$.

Results from FDS simulations, analytical model, and experimental data are plotted and compared in Figure 4. For Kurikka experiments, the analytical model gives a better approximation for experimental positive pressure peaks than FDS. Compared to experimental data, analytical model underestimated positive pressure peaks by 3%, 1.5%, and 12% for test 3, 5, and 8 respectively. FDS overestimated the experimental positive pressure peaks by 35%, 20%, and 17% for test 3, 5, and 8 respectively. Compared to FDS simulated pressure data, the analytical model estimated the peak positive pressures with a percentage difference of 39%, 6%, and 31% for test 3, 5, and 8 respectively.

Analytical model also approximates experimentally recorded pressure drop upon fire extinguishing better than FDS, as can be seen in Figure 4. Percentage differences in the observations are not given here, as pressure drop is not the focus of study here.

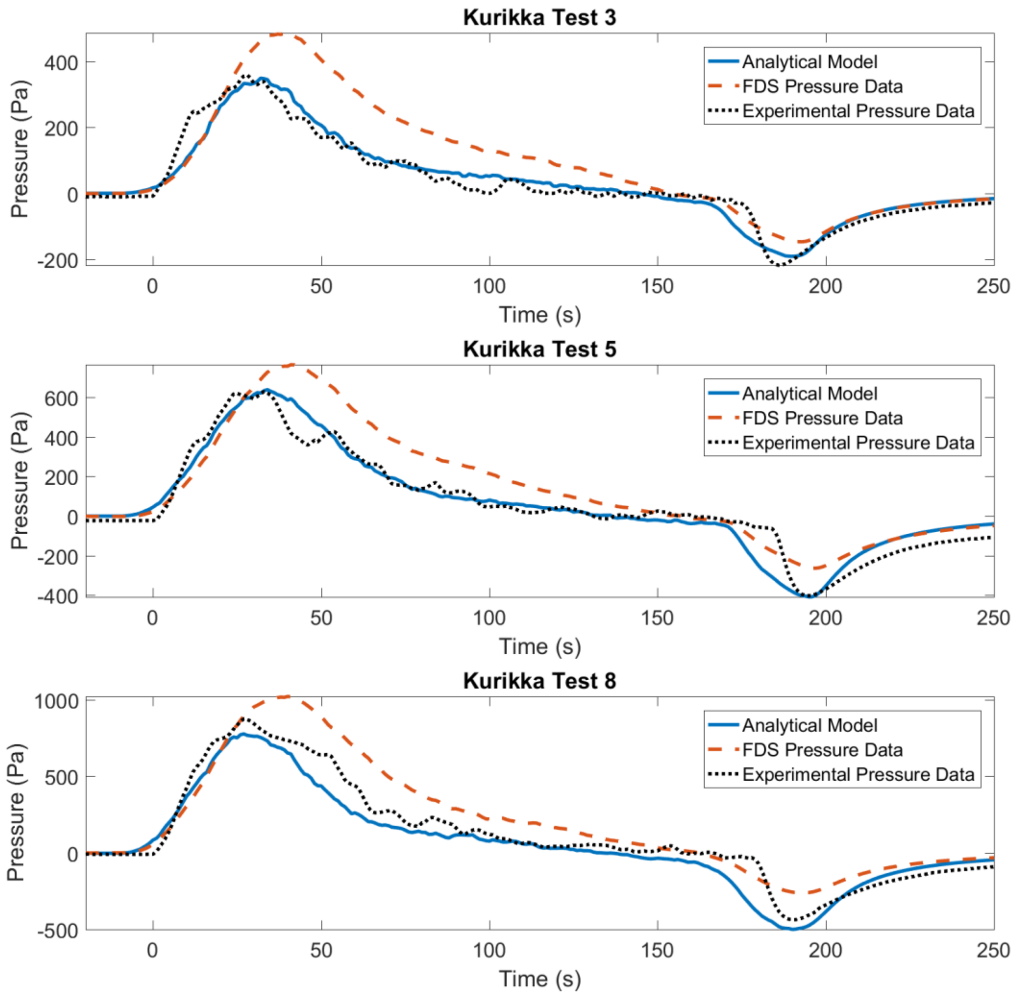

Figure 4: Validation plots for Kurikka Experiments

Overall, this model gives a sound basis to study the pressure behavior in event of enclosure fires, provided we know the average temperature increase in a compartment under fire given by a CFD simulation or some other numerical method. The proposed model is significant as it provides a basis to investigate different ventilation or leakage configurations without a need to re-compute the temperatures for every situation. This approach is valid if temperatures are assumed to be independent of varying leakage.

4. Methodology of Apartment Fire Studies

4.1. Apartment Fire Scenario Simulation Study[2]

Apartment fire scenario imitates realistic fire events occurring in residential settings. This scenario does not consider smoke travel to adjacent spaces and only focuses on the fire-induced pressures. Influence of fire growth rate, envelope airtightness and damper configuration on the fire-induced pressure in an apartment space is studied through the fire simulations in a hypothetical residential building.

The scenario is explored to reconfirm the variable trends observed by earlier studies. This study is unique as it investigates the impact of realistic fire growths over compartment pressure. The study also evaluates the risks involved with pressure rise in different scenarios (based on different variable states) and provides a basis to develop countermeasures.

The fire simulations depicting apartment fire scenarios were carried out using Fire Dynamics Simulator (FDS). Fire Dynamics Simulator (FDS) is a computational fluid dynamics (CFD) model of fire-driven fluid flow. The computer program solves numerically a large eddy simulation form of the Navier–Stokes equations appropriate for low-speed, thermally-driven flow, with an emphasis on smoke and heat transport from fires, to describe the evolution of fire. FDS is a FORTRAN program that reads input parameters from a text file, computes a numerical solution to the governing equations, and writes user-specified output data to files. Smokeview is a companion program that reads FDS output files and produces animations on the computer screen. For most applications, FDS uses a single step, mixing-controlled chemical reaction that uses three lumped species (a species representing a group of species). These lumped species are air, fuel, and products. The FDS-HVAC module models the ventilation network as a series of ducts and nodes. The nodes are placed at points where ducts intersect each other or the CFD computational domain. The ducts are uninterrupted domains of fluid flow, which can encompass elbows, expansion/contraction fittings, and various other fittings. The module does not presently store any mass. Therefore, mass flux into a duct is equal to the mass flux out of the duct. [20]

4.1.1. Building Description

The simulation geometry consists of a single floor in a hypothetical multi-story apartment building. The floor contains eleven apartments of two categories being nine $50m^2$ apartments and two $100m^2$ apartments and a corridor joining the apartments. The spaces are linked through a ventilation network, as can be seen in Figure 5, in which corridor is modeled to be at ambient pressure conditions. The floor ceiling height is 2.5 meters and the room walls and ceiling compose of 15 cm thick concrete. The fire is assumed to ignite in one of the smaller apartment. Within this apartment, the structures dividing the apartment into rooms are included, but the doors are assumed to be open. Model space only includes the interior of the envelope, hence, no effect of fire to or from outside is studied. The model does not include a staircase, connecting the domain to the other floors of the building, and the corridor pressure conditions are not studied.

[2] Apartment fire scenario was defined within PaHaHuPa project scope and Mr. Topi Sikanen of VTT first studied it.

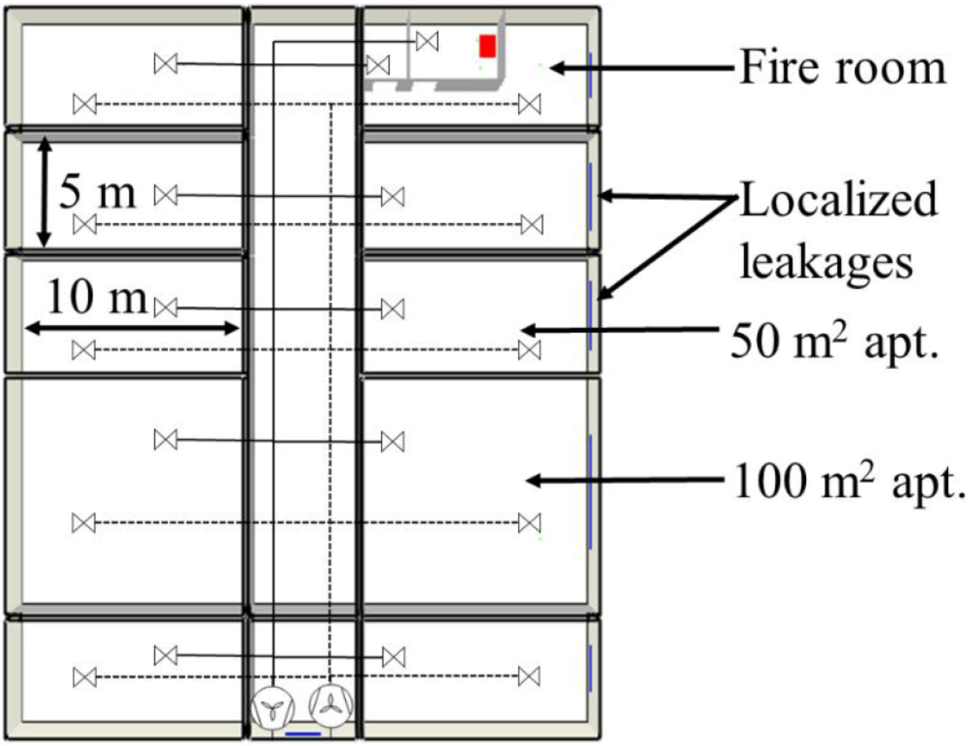

Figure 5: Geometry for the model apartment case study.[3]

4.1.2. Ventilation Network

Apartment ventilation network includes supply and exhaust networks to/from each room, having identical layouts, as shown in Figure 5. End of corridor links HVAC ducts to exhaust and inlet vents. The diameter of the central ducts is specified to be 250 mm and branches are designed as 125 mm diameter ducts. Two inlet and exhaust connections are designed for the fire apartment, but only one connection is modeled for the other apartments. Assuming mechanical ventilation, with a target air flow of ±40 l/s in 50 m^2 apartments and ±80 l/s in 100 m^2 apartments, a 'Quadratic' fan is used for both supply and exhaust networks. The fan has a stalling pressure of P_{max} = 550 Pa and a zero-pressure flow rate of V_{max} = 650 l/s. Model parameters for the fan unit are tuned to produce 150 Pa pressure loss to flow. The used fan curve is shown in Figure 6. Duct loss coefficients 'K' for the inlet and exhaust ducts are adjusted in non-fire conditions to achieve the targeted ventilation flow rates and also to keep the apartment at a slightly negative pressure. Losses corresponding to heat transfer coils and filters are also included.

[3] Simulation geometry is used after seeking permission of Mr. Topi Sikanen.

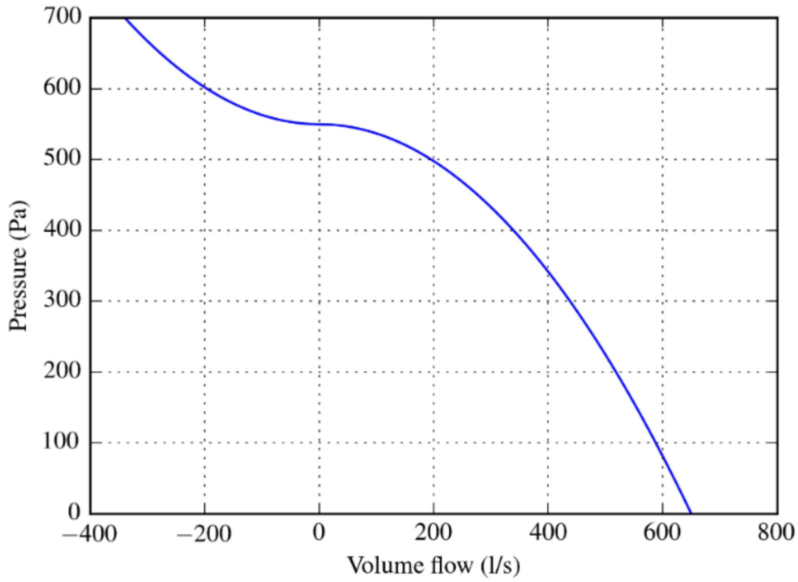

Figure 6: Fan curve used for the model apartment case study.

4.1.3. Simulation Model and Configurations

Each room in the model has a designated mesh. The discretization is 10 cm for the fire room and 50 cm elsewhere, meaning they only act as a volume reserve for pressure and gasses. Each room has its own designated pressure zone, with local leaks to ambient (outside or corridor). This is done to measure each room's background pressure solution individually. It is assumed that there is no heat transfer through the walls between the rooms and the leakages are to ambient only.

The influence of fire/smoke dampers installed in both supply and exhaust networks was studied. Fire dampers were assumed non-leaky and were activated 10s after fire starts. Dampers had three possible configurations being:

- **Damper = None**: Both inlet and outlet ducts remained open during the fire.
- **Damper = Inlet only**: A damper, 10s after ignition, closed the inlet duct of fire apartment.
- **Damper = Both**: Both inlet and outlet ducts of fire apartment were closed by dampers, 10s after ignition.

Envelope Airtightness

Three different air permeability values for building envelope were used in this study. Leakage measurements were assumed to correspond to a pressure difference of 50 Pa across the envelope. The used envelopes with their corresponding air permeability values are:

- A **Traditional** envelope with an air permeability (q_{50}) value of 3.0 m^3/m^2h.
- A **Modern** envelope with an air permeability (q_{50}) value of 1.5 m^3/m^2h.
- A **Near-zero** envelope with an air permeability (q_{50}) value of 0.75 m^3/m^2h.

Traditional value of permeability represents an average of the required and reference value for heat loss calculations given in the current Finnish building code (Part D3: Energy efficiency, 2012, Ministry of Environment). This is also equivalent to the Silver standard of Association of Environmentally Conscious Buildings (AECB) [13]. Modern leak rate corresponds to the measured air permeability values in the concrete element multistory buildings [15] and Silver E standard used in Canada [14]. The near-zero leak represents the current, technically achievable air permeability target value, also given as the Gold standard of AECB [13].

The volumetric leakage flow rate $\dot{V}_{50}$ at 50 Pa can be calculated from the air permeability and the surface area (S):

$$\dot{V}_{50} = \frac{q_{50}}{3600} S \left[\frac{m^3}{s}\right] \tag{24}$$

For a 50m^2 room, we used S = 175 m^2. The corresponding air exchange rate was calculated as $n_{50} = \dot{V}_{50}/V$, where V is the enclosure volume. The leakage areas A_L, through which these air-tightness levels were specified into the FDS models, were then calculated from the volumetric flow rates as:

$$A_L = \frac{\dot{V}_{50}}{C_d\sqrt{\frac{2\Delta P}{\rho_\infty}}} \left[m^2\right] \tag{25}$$

Leakage areas were calculated using a discharge coefficient of 0.6 and pressure difference of 50 Pa. For the simulation model, the calculated leakage areas were distributed equally at the locations of doors and windows such that all leaks opened up to ambient. The resultant envelope specifications are summarized in Table 1.

Table 1: Envelope Specifications

Envelope Type	q_{50} **[m^{3}m^{-2}h^{-1}]**	$\dot{V}_{50}$ **[m^3/s]**	n_{50} **[h^{-1}]**	A_L **[m^2]**
Traditional	3	0.146	4.2	0.02690
Modern	1.5	0.073	2.1	0.01345
Near-zero	0.75	0.036	1.05	0.00673

Design fires

The standard t^2-fire growth rate curves, given by National Fire Protection Association (NFPA), were used as design fires. Design fires were opted to remove any unknown effects from the pressure studies. A maximum HRR for the fires was kept to be 4 MW, as a realistic value for apartment fires [21]. The peak was kept high enough to consume the O_2 in the compartment and hence yield, both positive and negative pressure peaks. The three fire growth rates used for the residential fire scenario are given as follows:

- **Slow Fire**: $\dot{Q} = Q_o\left(t/t_g\right)^2$, t_g = 600 s, $\dot{Q}_{max} = 4MW$
- **Medium Fire**: $\dot{Q} = Q_o\left(t/t_g\right)^2$, t_g = 300 s, $\dot{Q}_{max} = 4MW$
- **Fast Fire**: $\dot{Q} = Q_o\left(t/t_g\right)^2$, t_g = 150 s, $\dot{Q}_{max} = 4MW$

where Q_o is normally chosen to be 1 MW (also in this case) [11]. Growth rates corresponding to 1 MW HRR are shown in Figure 7.

To input the design fires into the FDS simulations, heat release rate (HRR) was designated in terms of appropriate ramp factors at different time intervals. The fuel selected for this study was N-Heptane, having heat release rate per unit area (HRRPUA) of 1600 kW. Corresponding to the fuel chosen, the required fuel surface area to achieve the peak heat release rate (HRR) of 4 MW, was then calculated as shown in (26).

$$A_{\text{fuel}} = \frac{\text{Maximum HRR}}{\text{HRRPUA}} = \frac{4000\ \text{kW}}{1600\ {}^{\text{kW}}/_{\text{m}^2}} = 2.5\text{m}^2 \qquad (26)$$

The ramp factors respective of each fire type were next calculated and are shown in the underlying Figure 7, with 0 designating no fire and 1 designating peak fire HRR (4MW). The HRR ramp factors were also verified by carrying out simulations in a large space with sufficient oxygen.

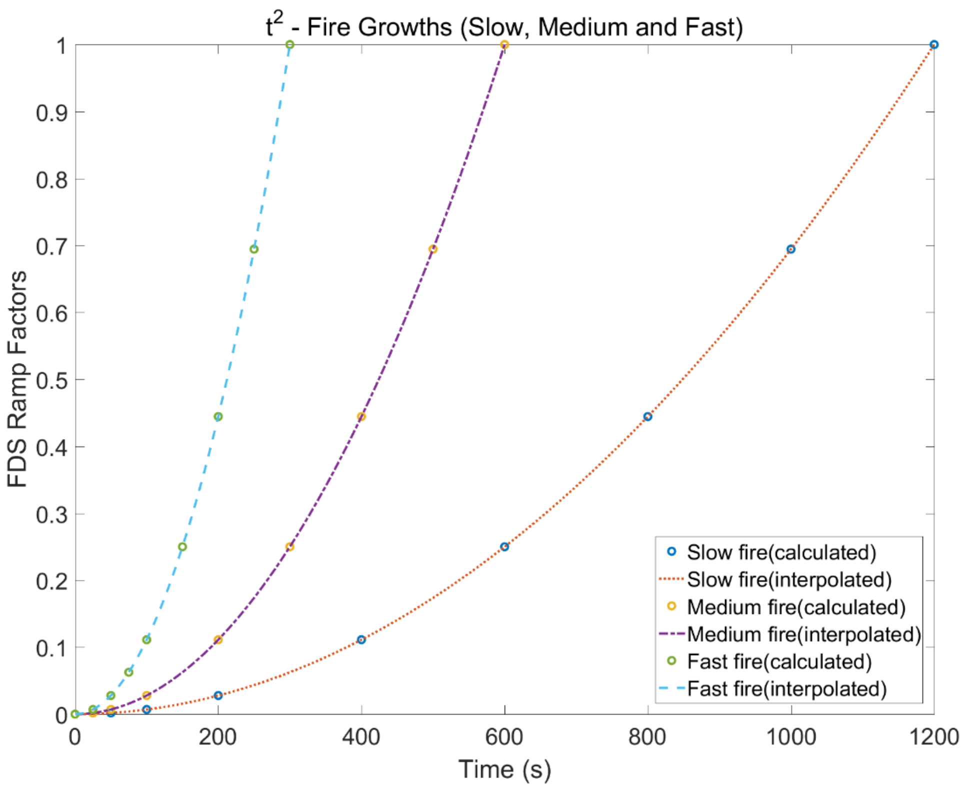

Figure 7: FDS Ramp factors for design fires

4.1.4. Simulation Matrix

For each fire type, using three different envelope leak rates and three different damper configurations, 9 simulation cases were studied making up to a grand total of 27 simulations. The resultant simulation cases are classified in Table 2.

Table 2: Case Study Extension Simulation Matrix

S/No.	Leak Rate	Damper Configuration	Fire Growth Rate
1	Traditional	None	Fast
2	Traditional	None	Medium
3	Traditional	None	Slow
4	Traditional	Inlet Only	Fast
5	Traditional	Inlet Only	Medium
6	Traditional	Inlet Only	Slow
7	Traditional	Both	Fast
8	Traditional	Both	Medium
9	Traditional	Both	Slow
10	Modern	None	Fast
11	Modern	None	Medium
12	Modern	None	Slow
13	Modern	Inlet Only	Fast
14	Modern	Inlet Only	Medium
15	Modern	Inlet Only	Slow
16	Modern	Both	Fast
17	Modern	Both	Medium
18	Modern	Both	Slow
19	Near-Zero	None	Fast
20	Near-Zero	None	Medium
21	Near-Zero	None	Slow
22	Near-Zero	Inlet Only	Fast
23	Near-Zero	Inlet Only	Medium
24	Near-Zero	Inlet Only	Slow
25	Near-Zero	Both	Fast
26	Near-Zero	Both	Medium
27	Near-Zero	Both	Slow

4.2. Apartment Fire Scenario Explored by the Analytical Model

The analytical model developed in Section 3.2, was applied to the apartment fire scenario as an attempt to capture the fire-induced overpressures alternatively. The focus of this study was to estimate the pressure rise in the fire apartment only.

4.2.1. Inputs for Apartment Fire Scenario

Time steps and average gas temperatures were obtained from the FDS simulations for every case presented in Table 2. The geometry is explained previously in Section 4.1.1, from where the geometrical inputs for the analytical model were extracted. Total fire room air volume was calculated to be:

$$V = Length * Width * Height = 10 * 5 * 2.5 = 125\ m^3$$

Equivalent Orifice Areas

The equivalent orifice areas corresponding to leakage measurements presented in Table 1, associated with all the three configurations are:

Traditional Leak Area

The equivalent orifice area for traditional envelope was:

$$A_{leak} = \frac{0.146\,\frac{m^3}{s}}{0.6 * \sqrt{\frac{2 * 50}{1.204}}} = 0.02690\ m^2$$

For FDS simulations, the equivalent orifice area was divided into two equal local leaks at doors and windows, having 0.01345 m^2 local leakage area each.

Modern Leak Area

The equivalent orifice area for modern envelope was found to be:

$$A_{leak} = \frac{0.073\,\frac{m^3}{s}}{0.6 * \sqrt{\frac{2 * 50}{1.204}}} = 0.01345\ m^2$$

For FDS simulations, the equivalent orifice area was divided into two equal local leaks at doors and windows, having 0.006725 m^2 local leakage area each.

Near-Zero Leak Area

The equivalent orifice area for near-zero leakage was found to be:

$$A_{leak} = \frac{0.036\,\frac{m^3}{s}}{0.6 * \sqrt{\frac{2 * 50}{1.204}}} = 0.006725\ m^2$$

For FDS simulations, the equivalent orifice area was divided into two equal local leaks at doors and windows, having 0.00336 m^2 local leakage area each.

Ventilation Duct Areas

Two ducts (One supply and one exhaust) were present in the fire room, both of which were considered as leak paths for the analytical model application. The diameter of the ducts in the fire apartment was set to be 125 mm (0.125 m) which gives the leak area of 0.01227 m^2.

Ventilation was controlled by the variable 'Damper', whose configuration decided whether the HVAC duct area was added into total leak area or not. The combinations are given in Table 3.

Table 3: Damper Controlled HVAC Duct Areas

Damper Configuration	Inlet Duct Area	Outlet Duct Area
None	0.01227 m^2	0.01227 m^2
Inlet Only	0 m^2	0.01227 m^2
Both	0 m^2	0 m^2

Total Leakage areas

Equivalent orifice areas and ventilation duct areas were combined into a total leak area for the envelope. In this way, all the leaks were converted into one leak path, which made the use of analytical model easier. A summary of leakage area calculation for every case is presented in Table 4.

Table 4: Total Leak Areas for the Simulation Matrix Cases

Leak	Damper	Leak Area [m^2]	HVAC Duct Area [m^2]	Total Leak Area [m^2]
Traditional	None	0.02690	0.02454	0.05144
	Inlet Only	0.02690	0.01227	0.03917
	Both	0.02690	0	0.02690
Modern	None	0.01345	0.02454	0.03799
	Inlet Only	0.01345	0.01227	0.02572
	Both	0.01345	0	0.01345
Near-Zero	None	0.006725	0.02454	0.031265
	Inlet Only	0.006725	0.01227	0.018995
	Both	0.006725	0	0.006725

Using the total leak areas, all the cases become comparable, as they all now respond to only one variable, making them easier to differentiate from each other and build a complete analysis over.

Discharge Coefficient

FDS models the leakage as a network of ducts and takes a default discharge coefficient of 1. For the apartment fire scenario simulation studies, a target ventilation rate of 25 l/s was set. The volume flow through the HVAC network was controlled using the LOSS term in FDS model. Altering the LOSS term changed the discharge coefficient accordingly. The relation between the discharge coefficient and LOSS term is [19]:

$$LOSS = (\frac{1}{C_d})^2$$

The three discharge coefficient values used for the analytical model, calculated based on the LOSS factor specified, are given in Table 5.

Table 5: Discharge Coefficients Used for the Analytical Model

Leak Path	LOSS Factor	Discharge Coefficient
Bulk Total Leak	1	1
Inlet HVAC Duct	14	0.267
Outlet HVAC Duct	7	0.3779

4.3. Pressure Management

Pressure Management refers to the discharge of fire-induced overpressures (under the threshold safety limits) to ensure the safe escape of occupants and the integrity of structures. The threshold pressure limit for the safe evacuation of occupants escaping through an inwards-opening door was assumed 100 Pa. This corresponds to a force equivalent weight of 10 kg per square meter, resulting in approximately 20 kg force for the modeled doors having an area of 2 m^2. For structural stability, on the other hand, from experiments like Kurikka [8], a noticeable threshold limit of 1500 Pa was estimated to prevent failure. This corresponds to a force of 153 kg per square meter.

Overpressure was managed by estimating the necessary additional leakage area, required to keep the fire-induced pressures under the threshold limits of occupant safety and structural integrity. Necessary additional leakage areas were calculated by employing the analytical model developed in Section 3.2. The findings were validated through FDS simulations. Additionally, the sensitivity of peak pressures relative to the envelope bulk leakage area was investigated. The study was limited to only fast fire with near-zero envelope case. Fast fire growth rate was selected for being the most realistic apartment fire scenario. Near-zero leak rate was selected on the basis that it yielded the highest pressures. Damper configurations were varied to exhibit different ventilation conditions.

5. Results and Discussions

5.1. Apartment Fire Scenario Simulation Results

Simulations were carried out using the FDS 6.3.0 version on an AMD Phenom II 3 GHz workstation with 8 GB RAM and 1000 GB hard drive. Simulation times were varying for each fire type, as the fast fire developed and diminished faster than the slow fire. For slow fire simulations, the average simulation time was 48 hours, for medium fire simulations the average simulation time was 11 hours, and for fast fires, the average time consumed was 8 hours.

5.1.1. FDS Pressure Curves and Observed Variable Trends

The captured pressure behavior from the simulation results is presented as Figure 8, Figure 9, and Figure 10 for slow, medium and fast fire respectively. FDS pressures were averaged over 25 seconds to reduce simulation noise and have been corrected for an estimated model bias factor of 0.87, calculated by the guidelines provided in [19].

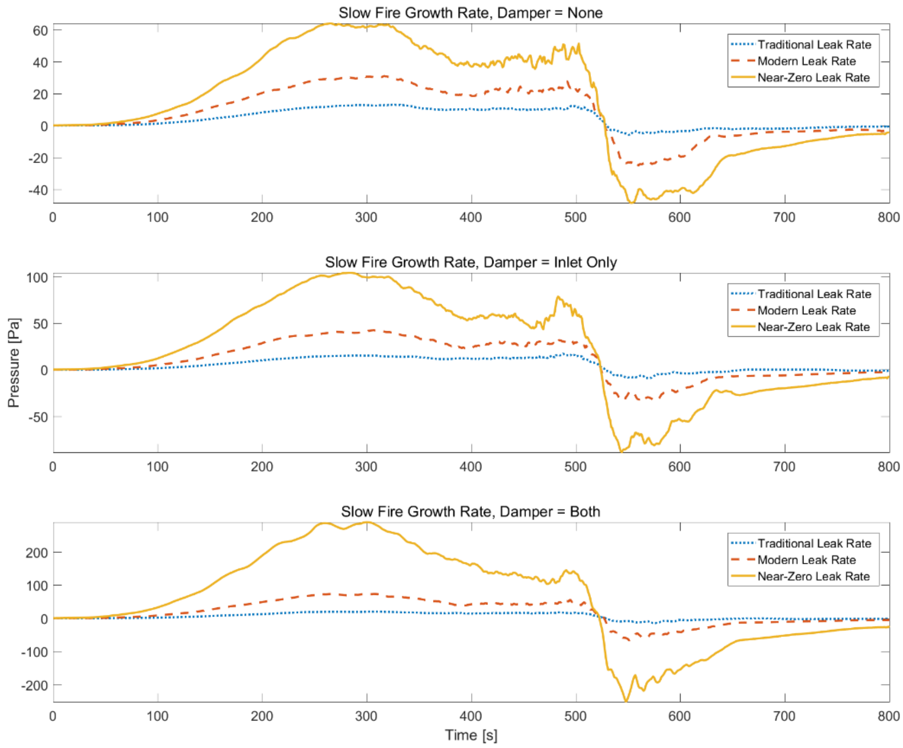

Figure 8: Slow Fire FDS pressure curves

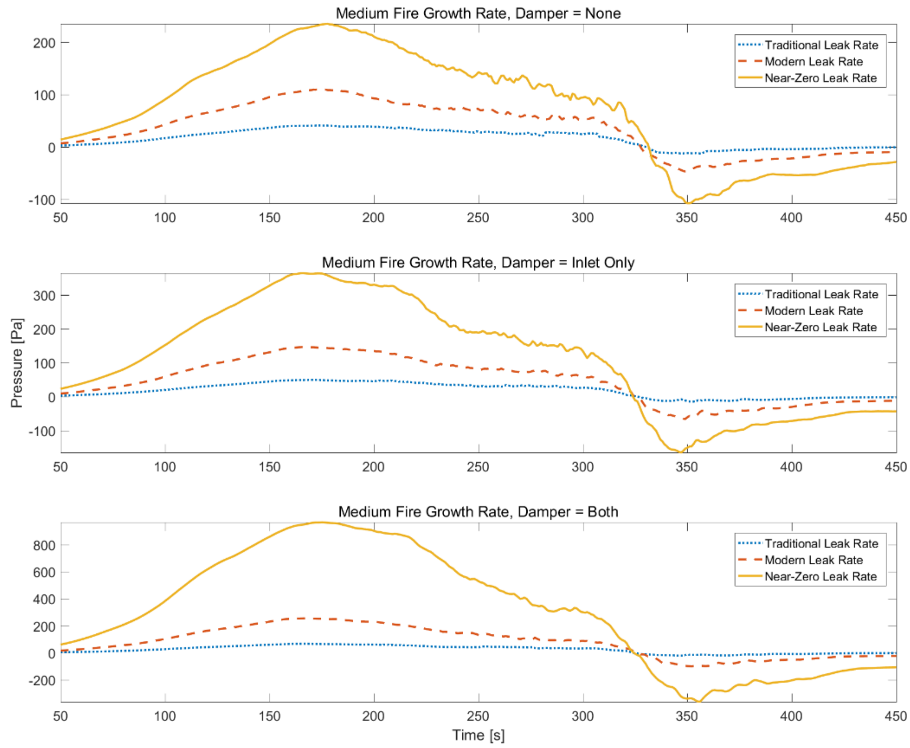

Figure 9: Medium Fire FDS Pressure Curves

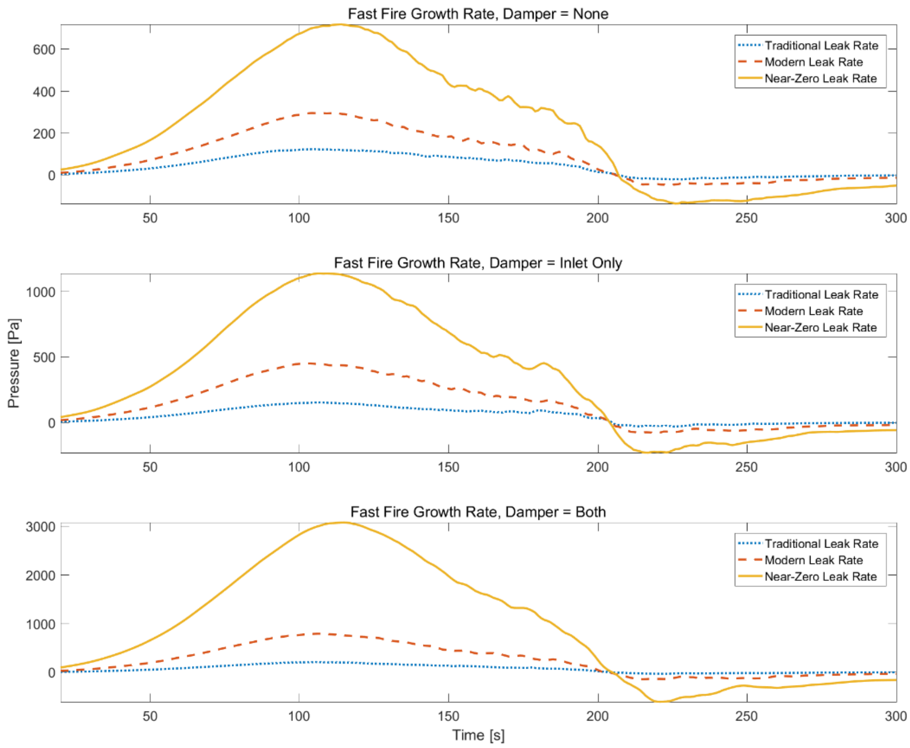

Figure 10: Fast Fire FDS Pressure Curves

Pressure rise was higher with better envelope airtightness (reduced envelope leakage rate) and damper involvement. Envelope leakage rate and damper configuration, together, control the overall air-tightness of the compartment. The highest pressures were encountered when the envelope had near-zero leak rate and damper was applied in both supply and exhaust ducts. Similarly, the lowest pressures were encountered for a traditional envelope with no dampers. This suggests that the pressure rise depends on the total leakage paths available in the compartment for pressure dissipation. As the leak paths are blocked or reduced, the pressure rises exponentially to the overall airtightness of enclosure, as shown in Figure 11. Trends for envelope airtightness and damper configurations reaffirm the findings of VTT case study.

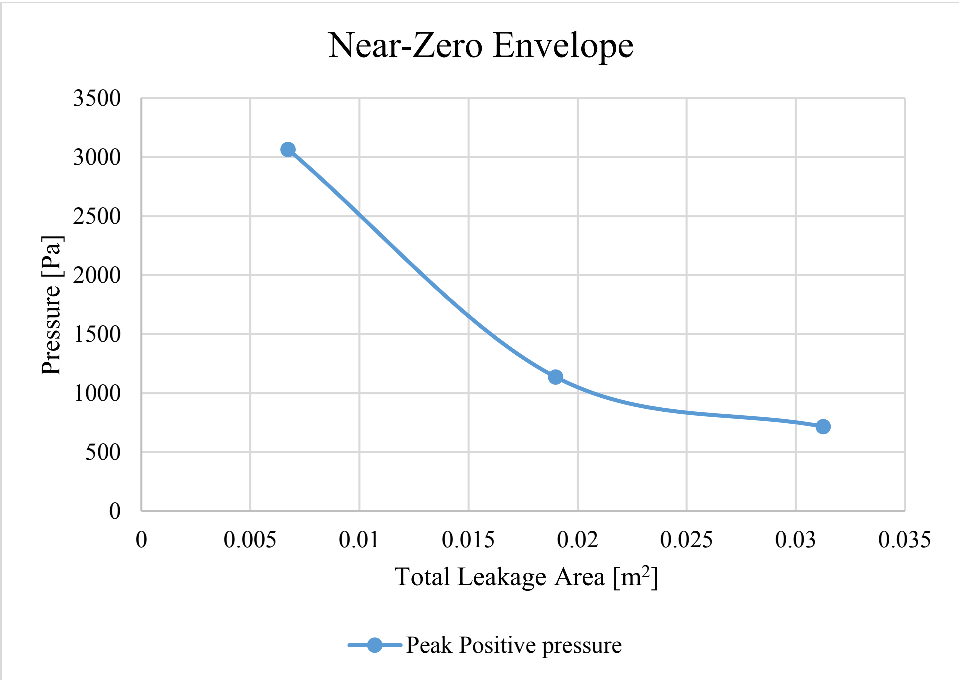

Figure 11: Exponential behavior of pressure relative to total leakage area

The pressure was found to be highly sensitive to the fire growth rate. The pressure rise was observed to be more apparent with increasing fire growth rate. This resulted in highest pressures for fast fire growth rate and lowest pressures for slow fires where pressures due to medium fire growth rate were found to be in the mid-range as shown in Figure 12. Pressure rise is higher for a shift from medium to fast fire than from slow to medium as shown in Figure 13.

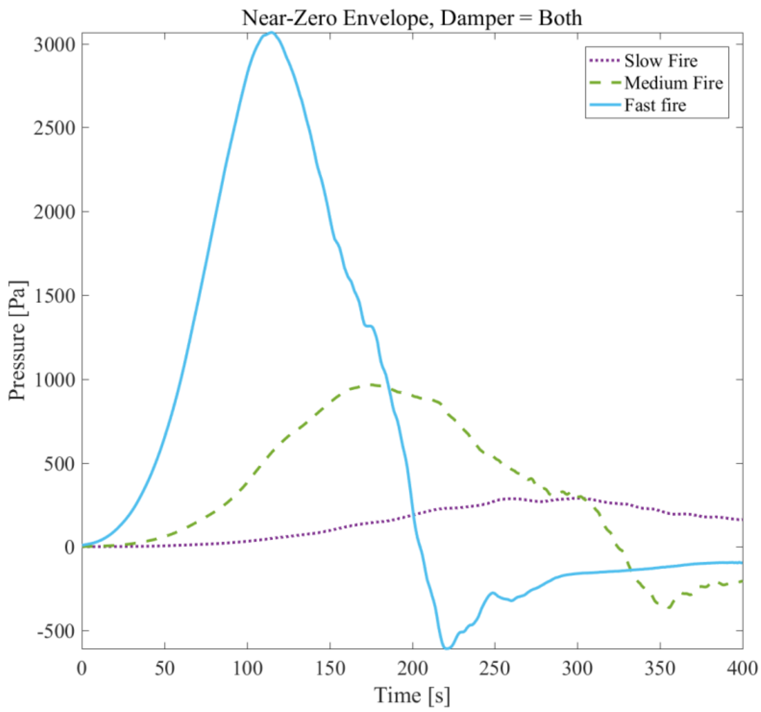

Figure 12: Variation in overpressure relative to fire type

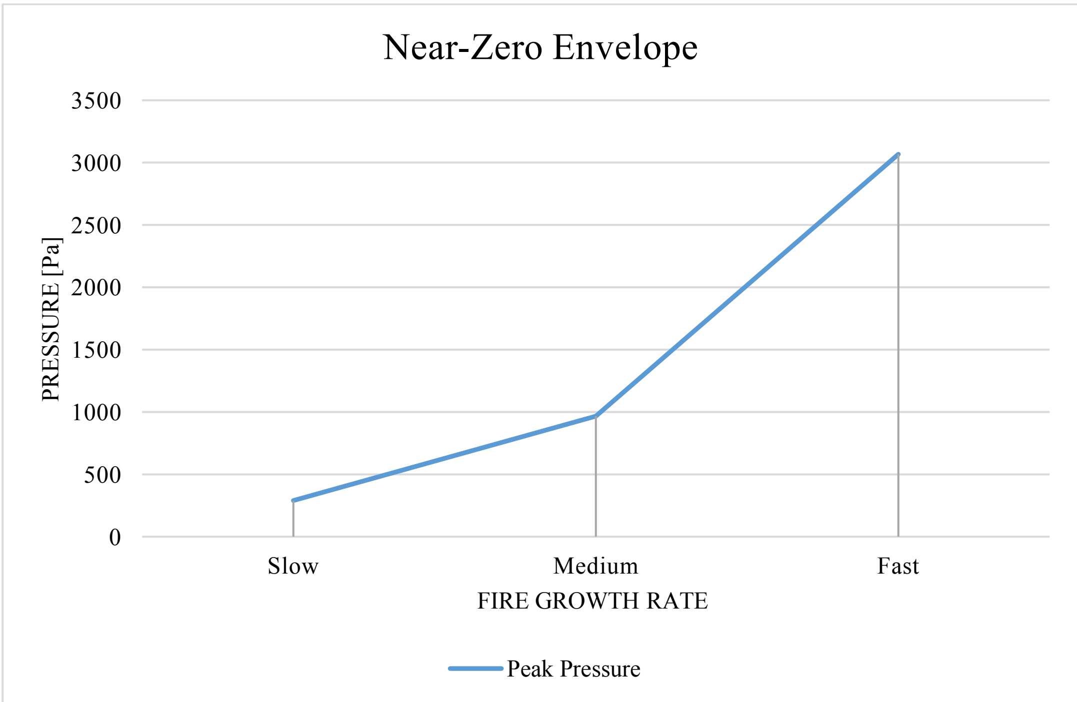

Figure 13: Exponential behavior of pressure relative to fire growth rate

5.1.2. FDS Simulated Peak Pressures

The observed peak pressures are summarized in Figure 14, Figure 15 and Figure 16 for slow, medium and fast fire respectively. The peak pressures were corrected for the estimated model bias of 0.87 and error bars were corrected for a standard deviation of 19%, evaluated based on the guidelines provided in the FDS validation guide [19].The error bars plotted for a standard doubled standard deviation indicate the 95% confidence limits for peak pressures.

The trends are consistent and clear for all three parameters – fire growth rate, envelope air-tightness, and damper configuration. Pressure is related directly to fire growth rate, damper application, and air-tightness of an envelope. The sensitivity of the pressure to a parameter value seems to increase when moving towards a faster fire growth or increased overall air-tightness of the compartment. For instance, the damper configuration is not too important for traditional buildings or slow fires but can become crucial for near-zero buildings or fast fires. Combined effect of all the variables can be summarized as, with the maximum confinement of hot gasses inside the enclosure, the highest pressures are developed. It is visible from the bar plots that the highest pressure of 3067 Pa was encountered with fast fire growth rate and near-zero envelope leak rate with damper applied on both supply and exhaust ventilation ducts. On the contrary, the lowest pressure of 13 Pa was observed under slow fire growth rate and traditional envelope with no damper involved. The observed variable trends validate previous studies like PRISME [3], Aalto Experiments [8] and VTT Case study. Therefore, dealing with the fire-induced pressures requires consideration of appropriate fire growth rate and overall air-tightness of the enclosure.

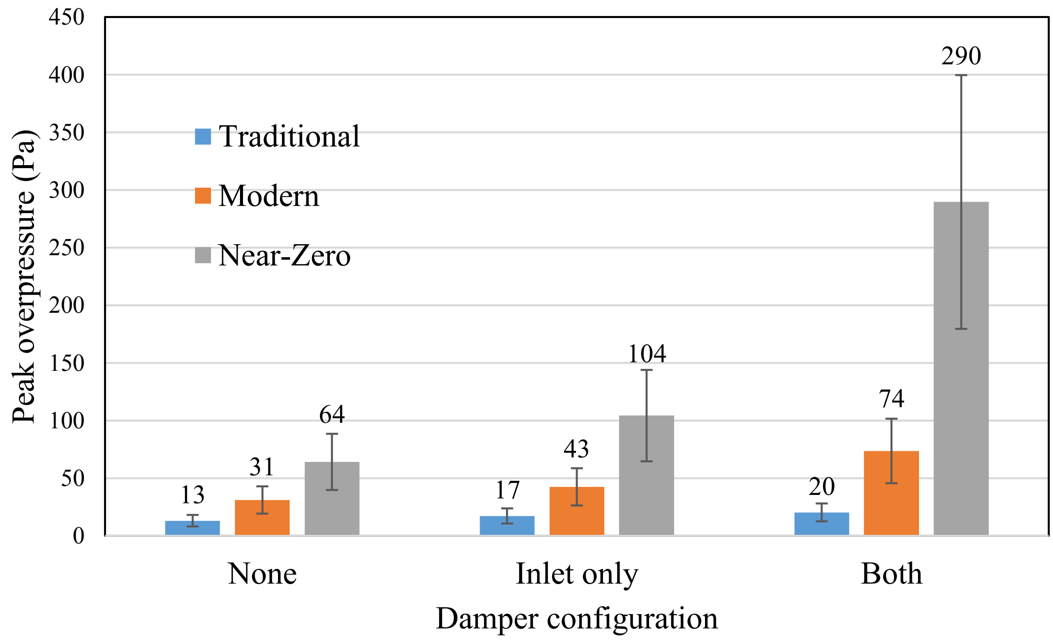

Figure 14: Slow fire peak pressures

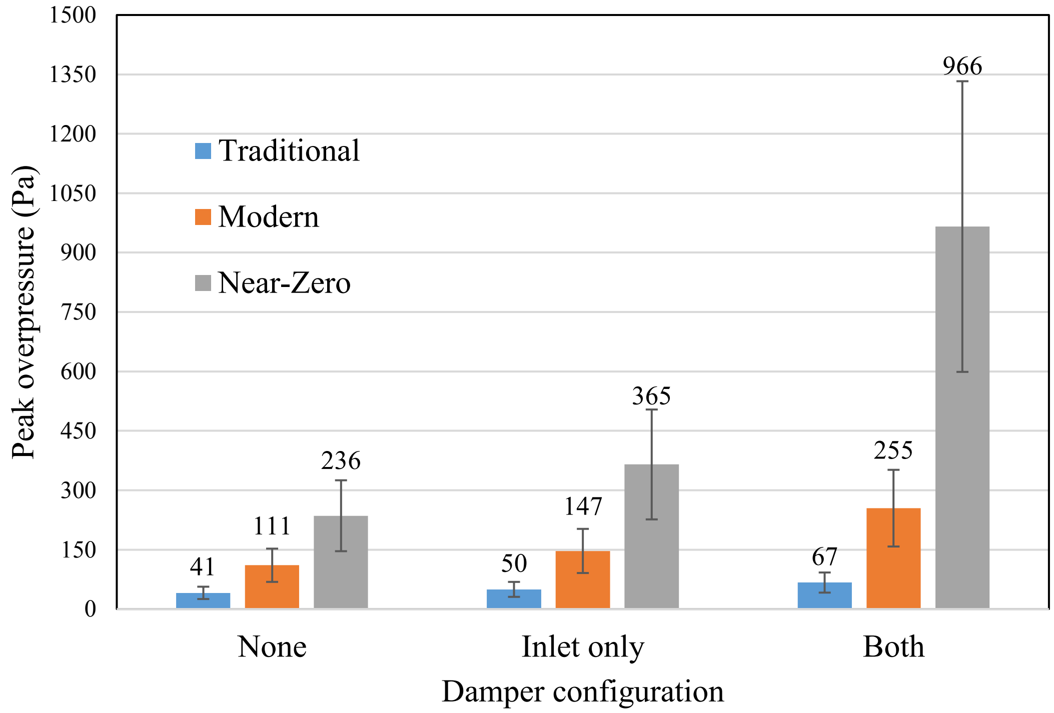

Figure 15: Medium Fire Peak Pressures

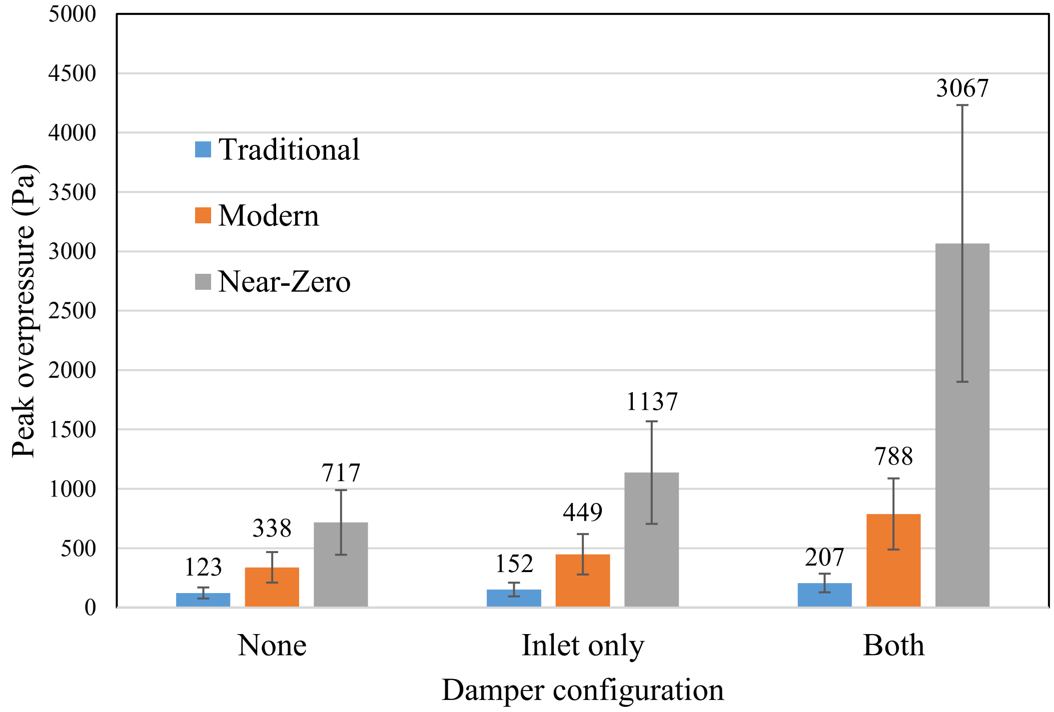

Figure 16: Fast Fire Peak Pressures

5.1.3. Time Measurements for 100 Pa Benchmark

To evaluate the occupant escape conditions, it is necessary to evaluate the times when the pressure rises above and when it falls below the threshold of 100 Pa. The measured time frames and intervals for all cases, where the threshold was reached, are listed in Table 6.

Table 6: Time measurements for 100 Pa Overpressure Benchmark

Fire Growth Rate	Envelope Type	Damper Configuration	Time [s], P > 100 Pa	Time [s], P < 100 Pa	Time Interval [s]
Fast Fire	Traditional	None	85	138	53
		Inlet Only	76	145	69
		Both	67	166	99
	Modern	None	55	191	136
		Inlet Only	48	195	147
		Both	38	198	160
	Near-Zero	None	40	203	163
		Inlet Only	33	201	168
		Both	21	203	182
Medium Fire	Traditional	None	-	-	-
		Inlet Only	-	-	-
		Both	-	-	-
	Modern	None	155	194	39
		Inlet Only	125	227	102
		Both	99	279	180
	Near-Zero	None	104	287	183
		Inlet Only	87	312	225
		Both	61	319	258
Slow Fire	Traditional	None	-	-	-
		Inlet Only	-	-	-
		Both	-	-	-
	Modern	None	-	-	-
		Inlet Only	-	-	-
		Both	-	-	-
	Near-Zero	None	-	-	-
		Inlet Only	-	-	-
		Both	159	470	311

For slow fire, only one case with near-zero envelope and both dampers applied crossed the 100 Pa threshold. It took a little above 2 minutes for the fire-induced pressure to cross the threshold and after an interval of around 5 minutes; the arisen pressure fell back under the threshold. For medium and fast fires, for most of the cases, the induced pressure exceeded the threshold. The times to reach 100 Pa overpressure were in the range of 61-155 s for medium fire and 21-85 s for fast fires. The durations of high pressure varied between 39 and 258 s. Generally, it was observed that the overpressure transgressed the occupant safety threshold pressure limit earlier in time for more airtight scenarios and faster fire growth rates. The pressure, also, stayed above the threshold limit for longer periods for the said configurations.

For the occupant safety threshold pressure limit of 100 Pa, it can be concluded that escaping should be possible from traditional buildings if the fire growth rate is medium or slower. For more airtight buildings and faster fires, opening the door would be challenging.

For the threshold pressure limit of 1500 Pa, structural integrity can be challenged if the fire development becomes fast or faster. We can observe in Figure 16 that structural safety is at risk when the envelope becomes very airtight. This situation is practically comparable to modern high-rise buildings.

5.2. Analytical Model Results

5.2.1. Model vs FDS Pressure Comparison Plots

In this section, the comparison is made between the pressure data obtained from the FDS simulations and the analytical model. The comparison plots of the two most relevant fire growth rates, being fast and medium, are presented in this section. The data is filtered over 25 seconds to reduce the simulation noise (data spikes) from the plots. FDS pressure data is also corrected for the estimated model bias of 0.87, evaluated based on the guidelines provided in the FDS validation guide [19].

Fast Fire

For the fast fire growth rate, comparison for all damper configurations was plotted for every envelope type. Figure 17, Figure 18 and Figure 19 present the comparison plots between analytical model and FDS simulation pressure curves for Traditional, Modern, and Near-Zero envelopes respectively.

The analytical model captured the pressure rise phenomenon, under an event of a fire within a compartment, with reasonable accuracy. The model, in general, overestimated the pressures as compared to FDS simulated pressures. Positive pressure peaks were captured closely. Negative peak pressure predictions showed significant differences, although the FDS predictions were found to have high uncertainty in this aspect.

The analytical model reproduced the trends observed in the FDS simulation results. This makes the analytical model a reliable tool for compartment fire studies.

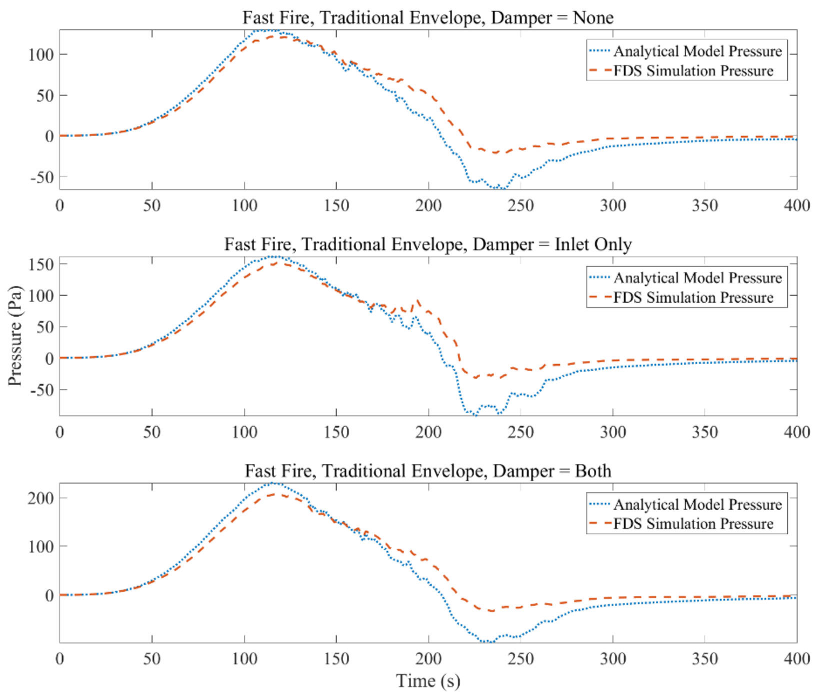

Figure 17: Comparison Plot for Fast Fire, Traditional Envelope

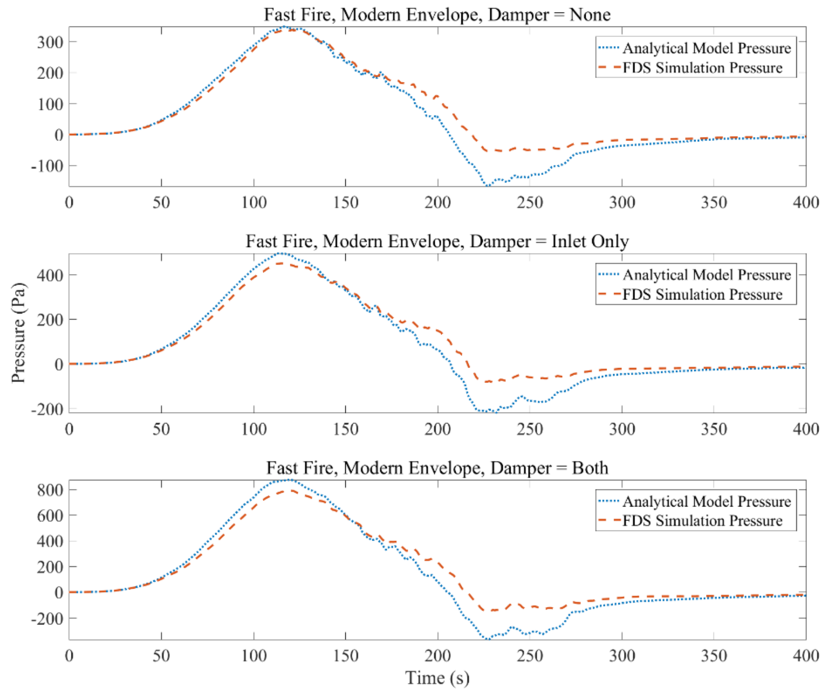

Figure 18: Comparison Plot for Fast Fire, Modern Envelope

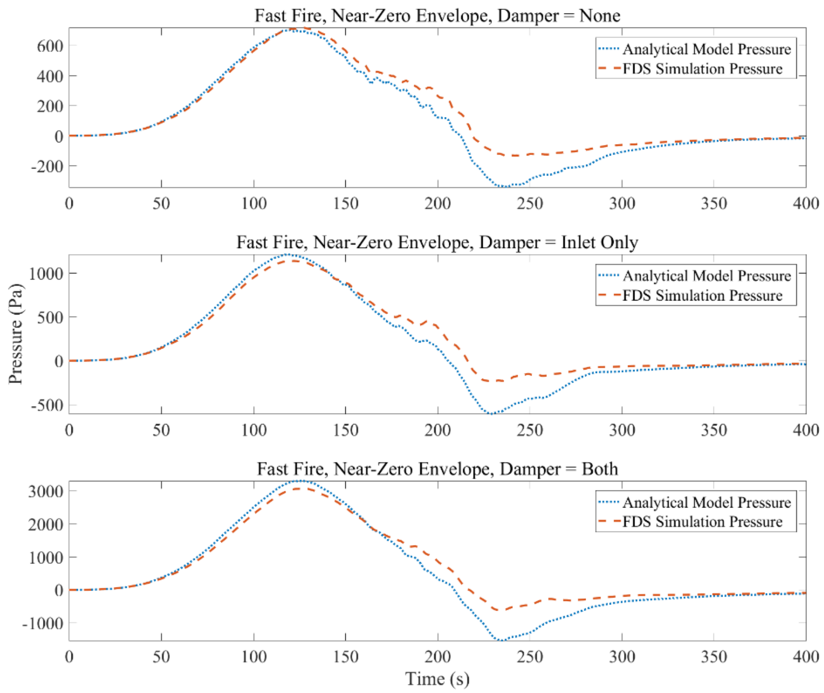

Figure 19: Comparison Plot for Fast Fire, Near-Zero Envelope

Medium Fire

For the medium fire growth rate, comparison plots with three damper configurations are presented in Figure 20, Figure 21 and Figure 22 for Traditional, Modern, and Near-Zero envelopes respectively.

For medium fire, the analytical model captured the compartment fire-induced pressure rise phenomenon reliably, as it did for the fast fire. In general, the model underestimated the pressure for medium fires. The model captured the positive peaks closely, but for negative pressure peaks, the model overestimated significantly. The variable trends were consistent, for medium fires too, relative to FDS simulations for all envelope types and damper configurations.

The medium fire comparison plots also suggested that the analytical model stood reliable even when the fire growth rate was changed. This means that the analytical model takes the variation of all relevant variables being fire growth rate, envelope airtightness, and damper configuration, into account. This favors the usability of an analytical model for compartment fire pressure studies.

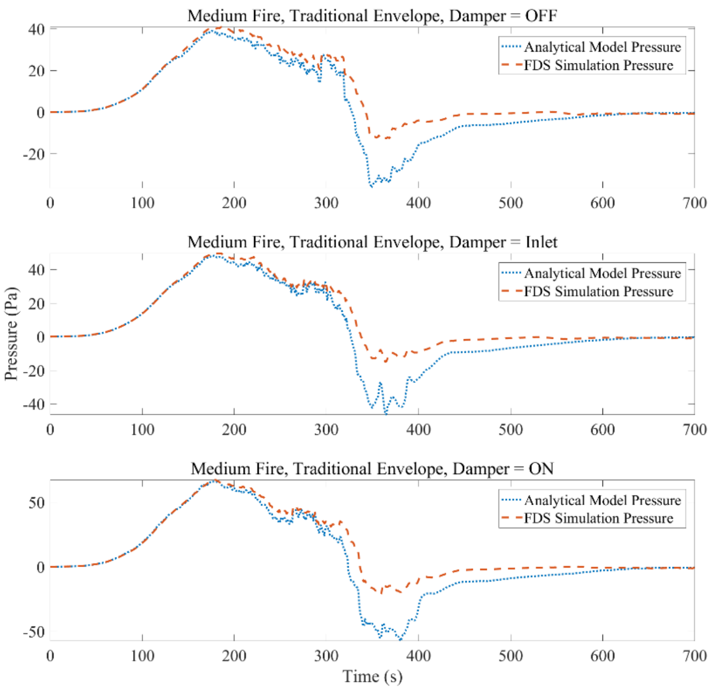

Figure 20: Comparison Plot for Medium Fire, Traditional Envelope

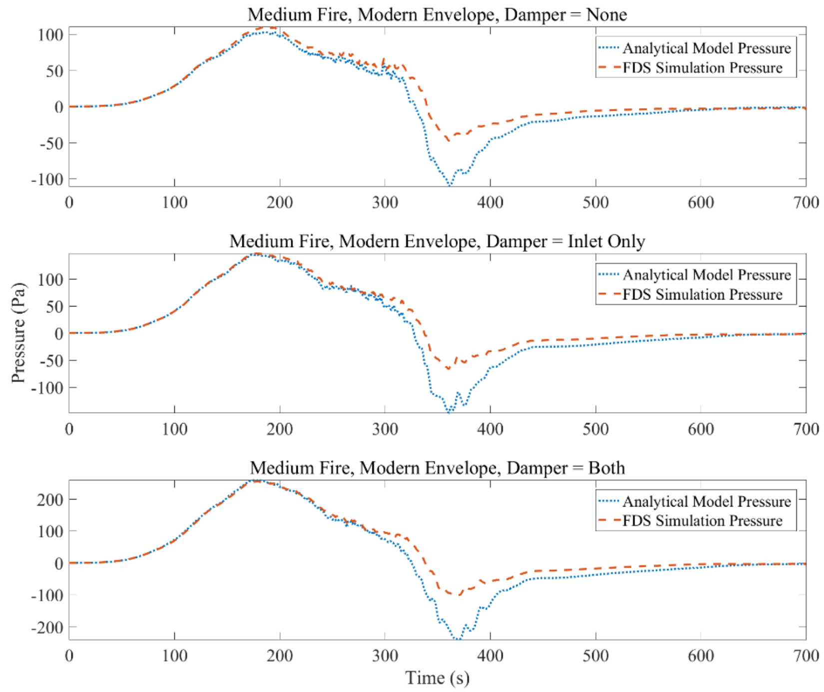

Figure 21: Comparison Plot for Medium Fire, Modern Envelope

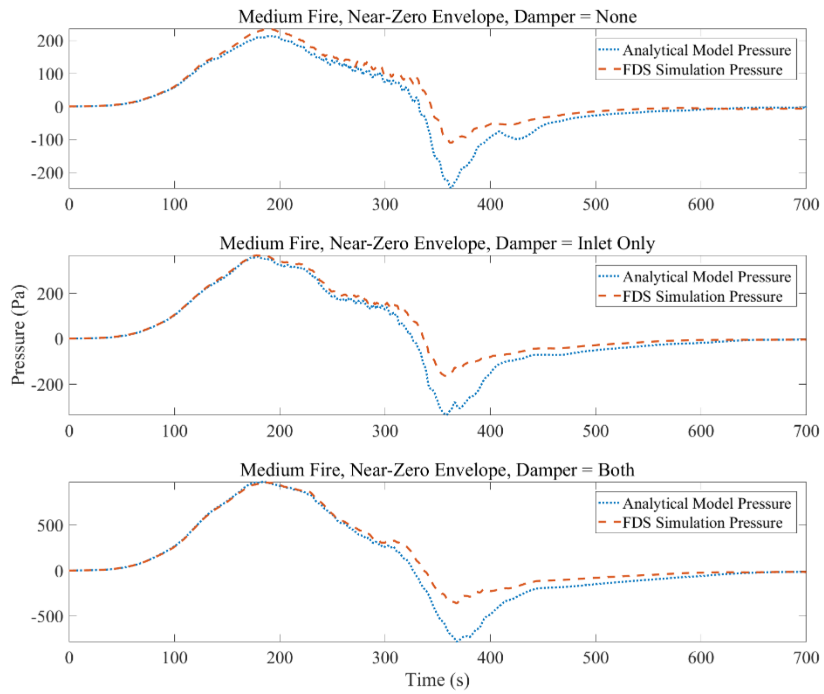

Figure 22: Comparison Plot for Medium Fire, Near-Zero Envelope

5.2.2. Positive Peak Pressures Comparison Charts

Comparative bar plots exhibiting positive pressure peaks captured by the analytical model and FDS simulations, for medium and fast fire growth rates, are presented in Figure 23 and Figure 24. The peak pressures are corrected for the estimated model bias of 0.87, evaluated based on the guidelines provided in the FDS validation guide [19]. Percentage differences for positive pressure peaks measured relative to FDS predicted peak pressures were calculated and are presented in Figure 25. It is visible that analytical model captured positive pressure peaks quite closely relative to FDS calculated positive pressure peaks.

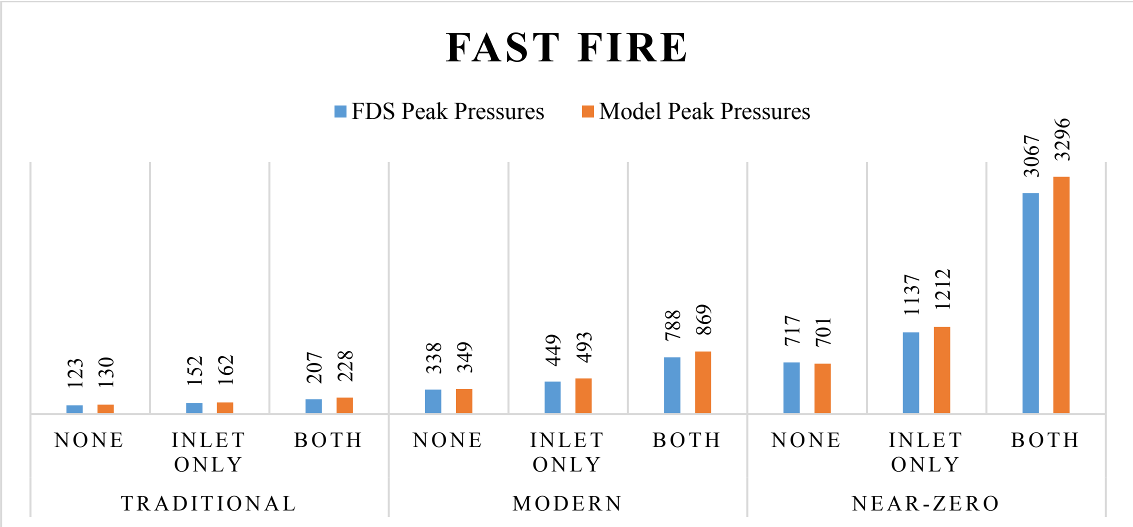

Figure 23: Peak Pressure Comparison for Medium Fires

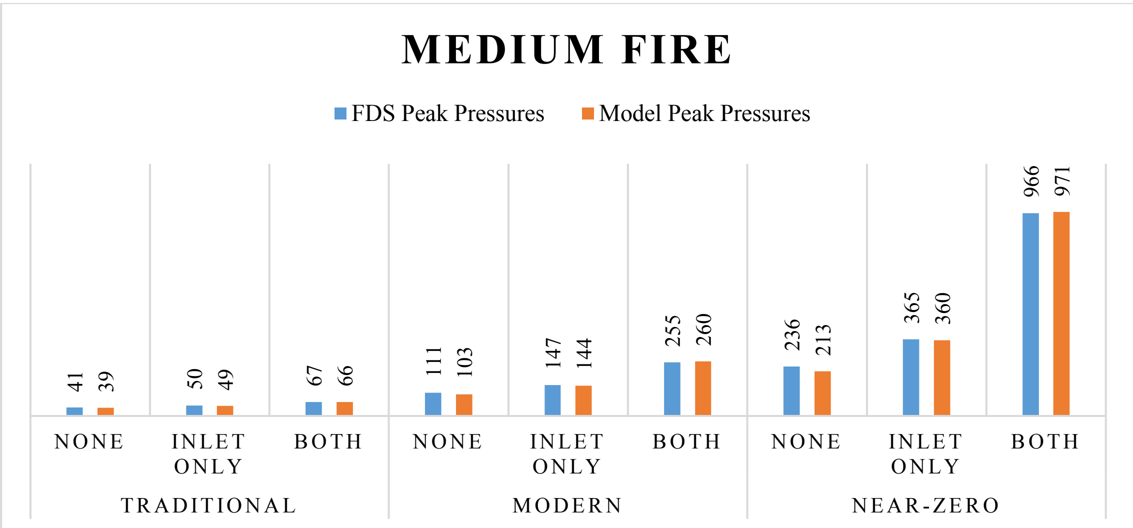

Figure 24: Peak Pressure Comparison for Fast Fires

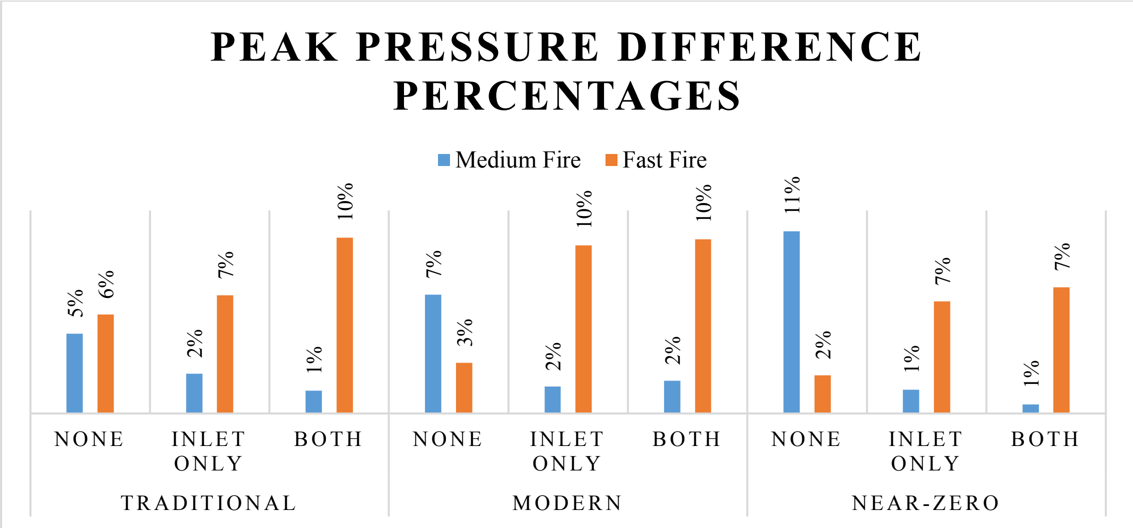

Figure 25: Percentage Differences for peak positive pressures

The overall relative difference lies within the limits of 1%-11%. The average overall relative difference for the peak pressures is 5%. For fast fire growth rate, the relative difference is higher than for medium fire growth rate. For medium fire only, the average relative difference is 4% and for fast fire alone, the average relative difference is 7%.

For fast fires, the relative difference increases for overall compartment tightness for example with the inclusion of dampers in the HVAC ducts the percentage difference increased. For medium fires, we see an inverse pattern in the relative differences. The relative difference decreases for overall compartment tightness for example with the inclusion of dampers in the HVAC ducts the percentage difference decreased. This suggests that the relative differences in pressure peaks calculated by analytical model and FDS simulations are dependent upon the fire growth rate as well as the overall air-tightness of the compartment.

The limitations endured by the analytical model are listed as follows:

- Analytical model shows higher uncertainty for a faster growth rate of fire, leakier envelope, and absence of dampers.
- The model requires average gas temperatures to compute compartment fire pressures. FDS simulations provided the temperatures used in this study. This makes the analytical model still dependent upon FDS simulations in a way.

Average gas temperatures, being the most important input, makes the model dependent upon FDS simulations. Alternative approaches such as analytical correlations and Zone models can be used to find the average gas temperatures without using the simulations.

5.3. Pressure Management Findings

5.3.1. Necessary Additional Leakage Area

Necessary additional leakage area is the minimum additional leak area required by a compartment to diminish the overpressures under the threshold pressure limits of occupant safety and structural integrity. The findings are based on the iterative studies employing the analytical model. The study is based on fast fire growth rate with near-zero leak envelope case because this configuration yielded the highest pressures. The calculated additional leak areas along with their associated opening diameters are given in Table 7. It was observed that making the enclosure more air-tight requires larger additional leak area to dissipate the fire-induced pressure under threshold pressure limits.

Table 7: Additional Leakage Area and Associated Diameters

Threshold Pressure [Pa]	Damper Configuration	Additional Leak Area [m^2]	Associated Diameter [mm]
100 pa	None	0.025	178.45
	Inlet Only	0.029	192.20
	Both	0.034	208.12
1500 Pa	Both	0.0036	67.72

The calculated additional leak areas were added to the envelope bulk leakage areas for the validation simulations. The comparative pressure plots for validation study are given in Figure 26 and Figure 27, for occupant safety and structural integrity cases, respectively. FDS pressures are corrected for the estimated model bias of 0.87, evaluated based on the guidelines provided in the FDS validation guide [19]. Comparative chart for the pressure peaks captured by analytical model and FDS simulations is given in Figure 28.

It was observed in the comparative pressure plots that the analytical model successfully replicated FDS simulations, even after adding the additional leakage area to envelope leakage area. The validation justified the use of the analytical model for pressure management studies. The reliability of the analytical model gives us the liberty of altering the inputs, as per need, to study the effect of changes in variable state.

Percentage differences between positive pressure peaks measured from analytical model and FDS simulations are given in Figure 29. It was found that the analytical model underestimated the peak pressures as compared to FDS simulated pressure peaks in general. The relative percentage differences between peak pressures for occupant safety threshold were below 6%. For the structural integrity threshold limit, the relative percentage difference between peak pressures was found to be 6%.

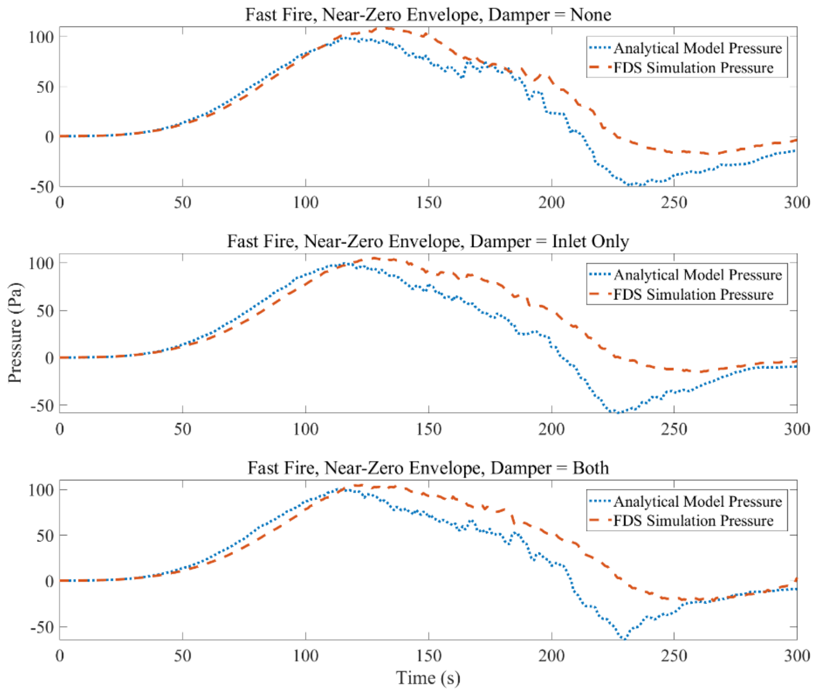

Figure 26: Pressure management validation for 100 Pa threshold pressure case

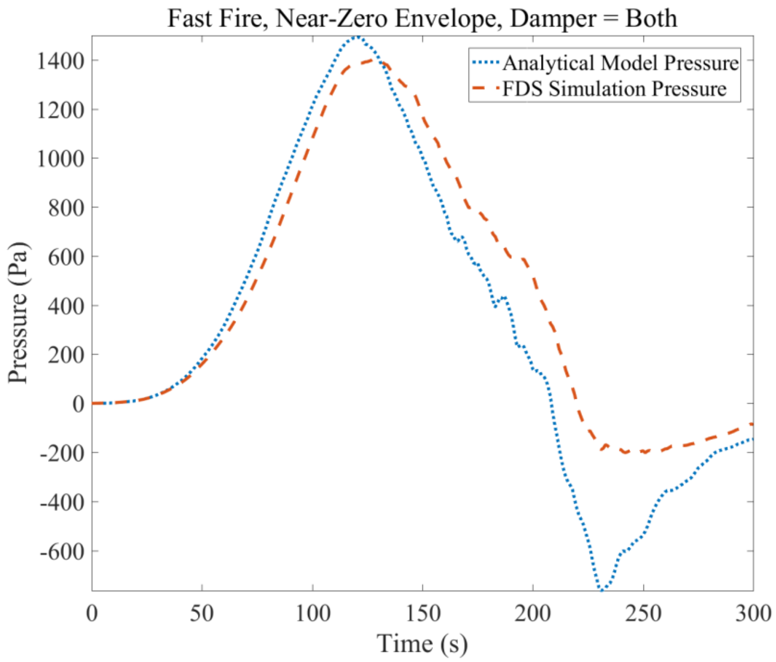

Figure 27: Pressure management validation for 1500 Pa threshold pressure case

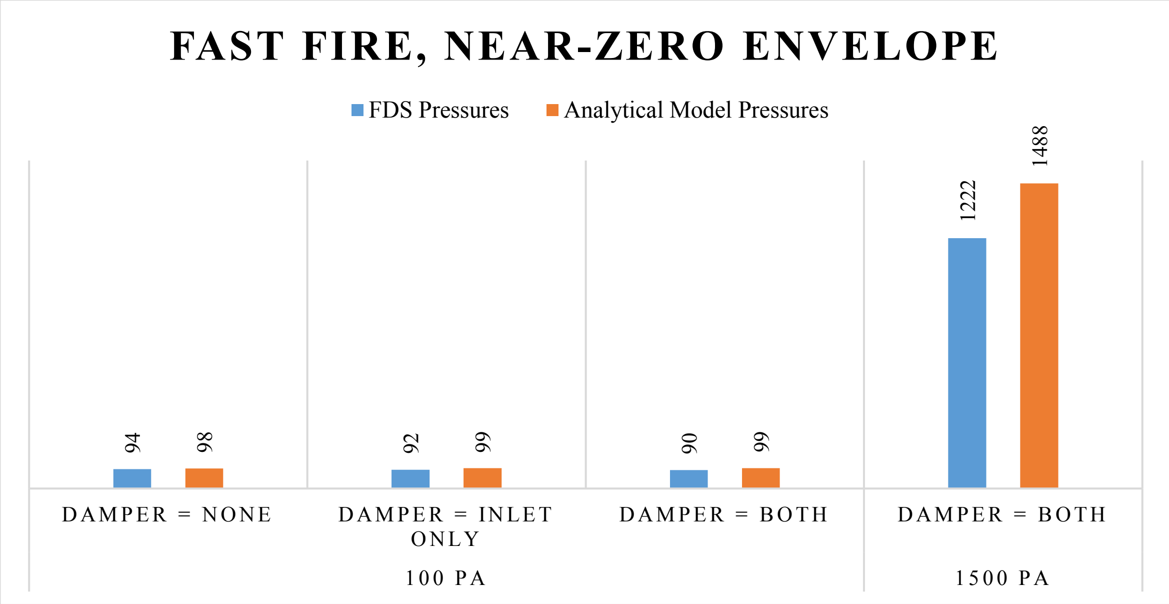

Figure 28: Additional Leakage Area Validation

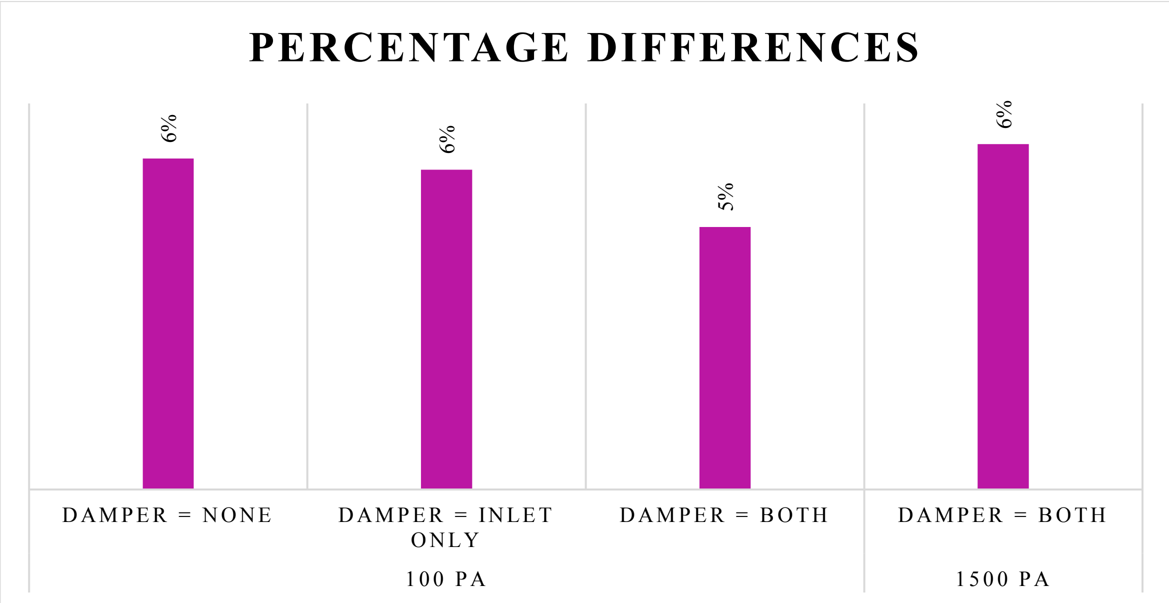

Figure 29: Percentage differences for Pressure Management Validation Study

5.3.2. Peak Pressure as a Function of Envelope Leakage Area

Based on the additional leak area estimation and its validation through FDS, the peak pressure as a function of envelope bulk leakage area was studied using the analytical model, for a Fast fire and Near-Zero envelope case. The relationship found between the peak pressure and envelope bulk leakage area is presented in Figure 30, Figure 31 and Figure 32 for the three damper configurations being None, Inlet Only, and Both, respectively. Peak pressure was found to be highly sensitive to the leakage area. Threshold pressure limits for occupant safety and structural integrity were converted into equivalent threshold limits for envelope bulk leakage areas and are demonstrated on the plotted curves.

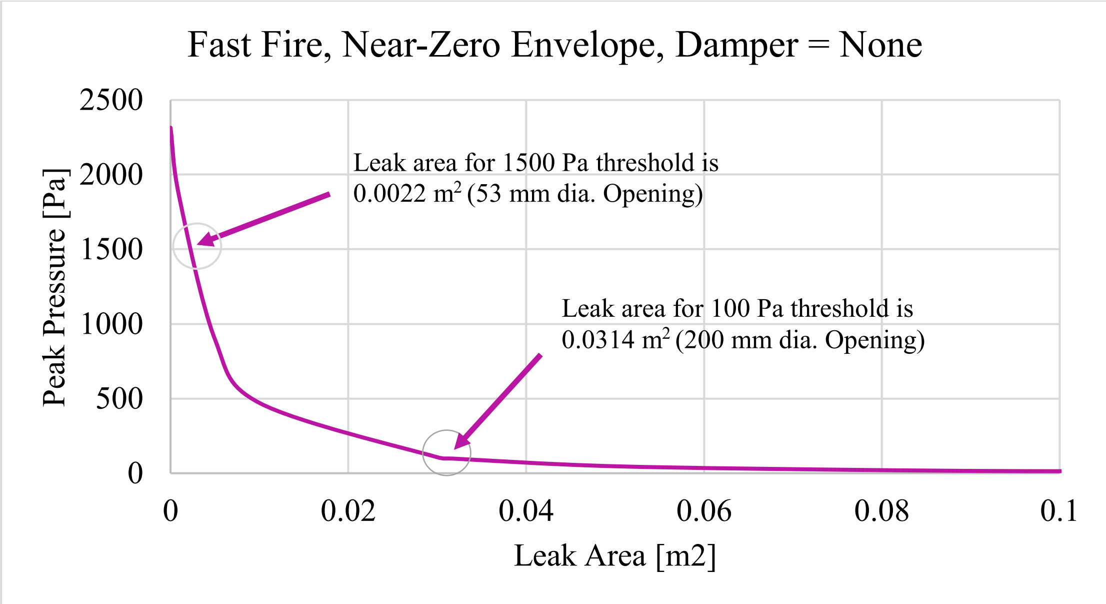

Figure 30: Threshold envelope bulk leak areas for damper = OFF configuration

The plotted curve clearly depicts the sensitivity of peak pressure to envelope leakage area with an indication of a leakage area threshold existing, such that, leakage area reducing below this threshold will result is much higher pressures. This happens because of the slope of curve changes drastically once threshold limit is crossed indicating that pressure is roughly exponentially related to envelope bulk leakage area.

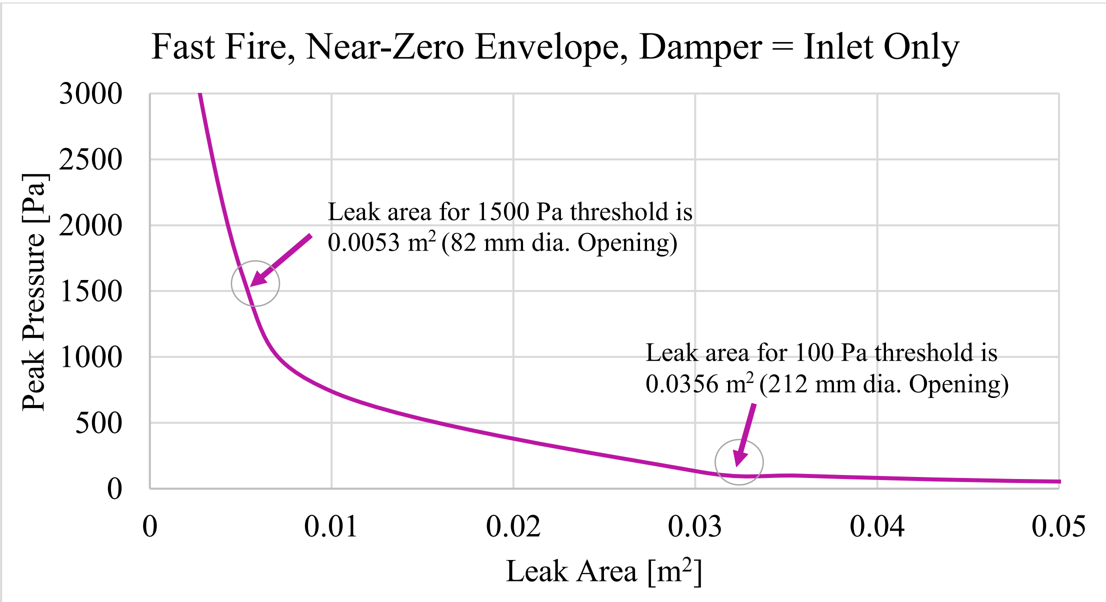

Figure 31: Threshold envelope bulk leak areas for damper = INLET configuration

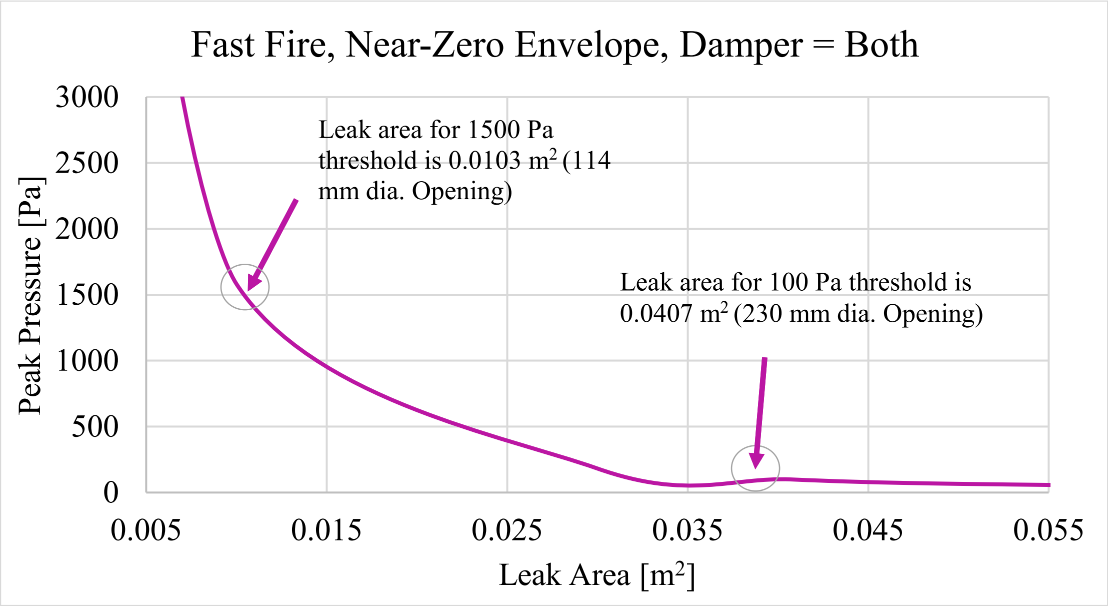

Figure 32: Threshold envelope bulk leak areas for damper = ON configuration

The equivalent envelope bulk leakage areas corresponding to the threshold pressure limits, for occupant safety and structural integrity, measured from the peak pressure curves plotted relative to leakage area, are summarized in Table 8.

Application of dampers results in an increase in the envelope bulk leakage area equivalent to occupant safety and structural integrity thresholds, as shown in Figure 33. This suggests that the application of dampers increases the sensitivity of peak pressure relative to leakage area. This reconfirms the risks involved with the modern day construction trends, where the increased envelope airtightness can cause the fire-induced pressures to become significant enough to pose threats to occupant safety as well as the structural integrity.

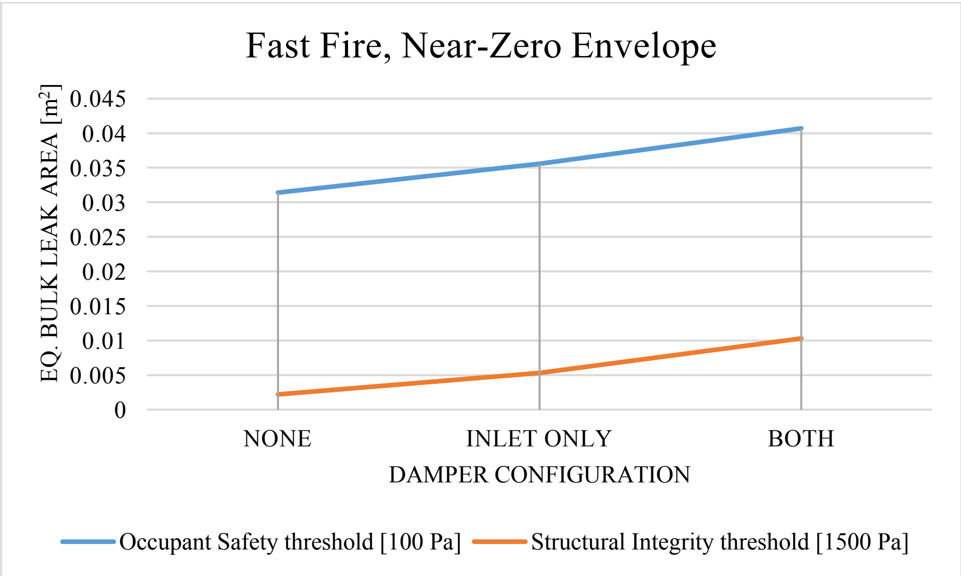

Figure 33: Equivalent Envelope Bulk Leak Area vs Damper Application

Table 8: Equivalent Envelope Bulk Leakage Area Thresholds Limits for Pressure Threshold Limits

Damper Configuration	Objective	Threshold Pressure Limit [Pa]	Equivalent envelope bulk leak area [m2]	Equivalent opening diameter [mm]
None	Occupant Safety	100 Pa	0.0314	200
	Structural Integrity	1500 Pa	0.0022	53
Inlet Only	Occupant Safety	100 Pa	0.0356	212
	Structural Integrity	1500 Pa	0.0053	82
Both	Occupant Safety	100 Pa	0.0407	230
	Structural Integrity	1500 Pa	0.0103	114

6. Conclusions

Fire-Induced pressure in closed but mechanically ventilated enclosures was studied through numerical simulations. The apartment fire scenario, initiated by VTT, was extended towards more realistic fire growth rates. Pressure rise as a function of the fire growth rate, envelope airtightness, and damper configuration was studied in 27 different scenarios. An analytical model was also developed as an alternative to the FDS simulations for predicting the over pressures in compartment fire scenarios. The results of the analytical model were compared against the FDS simulation results for the model reliability evaluation. Finally, the overpressure was managed through designing additional leakage areas to ensure occupant safety and structural integrity. The management studies also incorporate the peak pressure behavior as a function of the envelope leakage area.

Based on the simulation results, it was observed that the fire-induced pressure was roughly exponentially related to fire growth rate, envelope leakage area, and damper application. The observed trends state that with increasing fire growth rate, the pressure rise becomes more apparent. The highest pressure of 3067 Pa was encountered with the fast fire growth rate in the most airtight (low envelope permeability) compartment with dampers closed in both inlet and outlet ducts. On the contrary, a pressure of 13 Pa was recorded for a slow fire in a traditional envelope with no dampers applied to the ventilation ducts. It was inferred that the pressure rise depends on the total leakage paths available in the compartment for pressure dissipation. The sensitivity of the pressure to the parameter values increased while moving towards a faster fire growth or increased overall air-tightness of the compartment. For instance, the damper configuration is not too important for traditional buildings or slow fires but can become crucial for near-zero buildings or fast fires.

Occupant safety and structural integrity risks were analyzed against threshold pressure limits of 100 Pa and 1500 Pa, respectively. The time estimations suggested that the occupant safety threshold limit was breached earlier in time for more airtight scenarios and faster fire growth rates. The overpressure also stayed above the threshold limit for longer periods for the said case, which can hinder the occupant escape from the building under fire. Medium and fast fires in modern and near-zero envelopes were identified as risky scenarios for the occupants' safe egress. For the highest overpressure combination, the pressure exceeded the occupant safety threshold in just 21 seconds and compartment stayed over pressured for 3 minutes. Structural integrity was also found to be at threat under this case as the overpressure breached the structural integrity threshold pressure limit.

The developed analytical model captured the compartment fire-induced pressure rise with reasonable accuracy. The analytical model also captured the trends observed in the FDS simulations. Based on the validation study results, it was observed that the positive pressure peaks, in general, were over-estimated by the model for fast fires and underestimated for medium fires. The overall difference of analytical model pressure peaks relative to FDS peaks lies within the limits of 1%-11% and averages about 5%. For medium fire growth rate, the relative difference is lower than for fast fire growth rate. For medium fire, the average relative difference is 4% and for fast fire, the average relative difference is 7%. The relative difference decreased for overall enclosure airtightness for medium fires but increased for fast fires. This suggests that the accuracy of the model is dependent upon the fire growth rate as well as the overall air-tightness of the compartment.

The pressure management studies suggested that for the more air-tight enclosures, larger additional leak areas are required to diminish the fire-induced pressure under the threshold pressure limits. Peak pressure was found to be highly sensitive to the leakage area. Employing the pressure plots, the bulk leakage areas corresponding to the threshold pressure limits of occupant safety and structural integrity were estimated. This can help the designers to control the overpressure in fire scenarios.

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Appendix 1: Analytical Model Matlab function

```
    function [ p ] = pressure(t,T,V,Cd,A)
    %PRESSURE function calculates enclosure pressure assuming gas heating
%
%    Syntax
%    p = pressure(t,T,V,Cd,A)
%
%    Input arguments
%    t = time(s)
%    T = Temperature (K)
%    V = Volume (m3)
%    Cd = flow coefficient (-)
%    A = vent area (m2)
%
%    Output arguments
%    p = enclosure pressure difference from ambient (Pa)
%


%
% Define the equation to solve
%f = @(p2,p1,pamb,V,C,T2oT1) p2*(V+C*sign(p2-pamb)*sqrt(2*abs(p2-pamb)))-
(p1*T2oT1*V);%Fire Flow Formula
f = @(p2,p1,pamb,V,C,T2oT1) p2-p1*exp(-C*sign(p2-pamb)*sqrt(2*abs(p2-
pamb))/V)*T2oT1;%Mass Conservation Formula



pamb = 101317.38;
p(1) = pamb;

for n = 2:length(t)
    dt = t(n)-t(n-1);
    T2oT1 = T(n)/T(n-1);
    rho = 353/T(n);
    Ca = Cd*A/sqrt(rho);
    C = Ca*dt;
    p1 = p(n-1);
    p(n) = fzero(@(p2) f(p2,p1,pamb,V,C,T2oT1), p1);
end
p = p-pamb;
```

Appendix 2: FDS Input file

Input FDS File for Fast fire with Near-Zero envelope and damper applied in supply and exhaust ducts.

```
&HEAD CHID="PaHaHuPa_Near-Zero_dampers_on", TITLE="Geometria PaHaHuPa Case Studies"/
&TIME T_END=400, T_BEGIN = 0/
&SURF ID='Ovi', COLOR='BROWN'/
&SURF ID='Ikkuna', COLOR='BLUE'/
&MISC TMPA=20.0 /
&DUMP SMOKE3D=.TRUE.,
    NFRAMES= 100,
    DT_PART=1.0,
    DT_HRR =1.0,
    DT_DEVC =1.0,
    DT_SLCF=2.0,
    DT_BNDF=1000000.0,
    DT_PL3D=1000000.0,
    DT_ISOF=1000000.0 /  time steps for the outputs
&PRES MAX_PRESSURE_ITERATIONS=10,
    VELOCITY_TOLERANCE=0.01,
    CHECK_POISSON=.TRUE.,
    RELAXATION_FACTOR=1 , /
----------------------------------------------------------------------------------------
Fire:
&REAC FUEL='N-HEPTANE',
    CO_YIELD = 0.01, SOOT_YIELD = 0.037
    FYI= 'Heptane C_7 H_16' /
    Drysdale, D., An Introduction to Fire Dynamics, 3rd Edition, Wiley 2011
    Table 6.2, page 233: n-Heptane AIT, 255 C, 248 C, 223 C different sizes
    of the vessel. => 250 C is good enough for us.
&SURF ID= 'fire1', HRRPUA=1600, RAMP_Q='PoolRamp1', COLOR='RED', TMP_FRONT=98.0,/
&RAMP ID='PoolRamp1', T=0,       F=0.0 /
&RAMP ID='PoolRamp1', T=10,      F=0.00111020191452991/
&RAMP ID='PoolRamp1', T=30,      F=0.010000659042735/
&RAMP ID='PoolRamp1', T=50,      F=0.02778/
&RAMP ID='PoolRamp1', T=70,      F=0.0544448967863248/
&RAMP ID='PoolRamp1', T=100,     F=0.111111/
&RAMP ID='PoolRamp1', T=130,     F=0.187777864786325/
&RAMP ID='PoolRamp1', T=150,     F=0.25/
&RAMP ID='PoolRamp1', T=170,     F=0.321111097264957/
&RAMP ID='PoolRamp1', T=200,     F=0.4444445/
&RAMP ID='PoolRamp1', T=250,     F=0.6944445 /
&RAMP ID='PoolRamp1', T=300,     F=1.0 /
&RAMP ID='PoolRamp1', T=350,     F=0.0 /
&RAMP ID='PoolRamp1', T=400,     F=0.0 /
 ----------------------------------------------------------------------------------------
Materials:
&MATL ID= 'CONCRETE',
    FYI= 'Quintiere, Fire Behavior, Table 7.6'
    CONDUCTIVITY  = 1.700000,
    SPECIFIC_HEAT = 0.75,
    DENSITY       = 2200. /
&SURF ID        = 'ApartmentWall',
   MATL_ID    = 'CONCRETE',
   COLOR      = 'SILVER',
   BACKING    = 'EXPOSED',
   THICKNESS  = 0.15 /
&SURF ID        = 'OuterWall',
   MATL_ID    = 'CONCRETE',
   BACKING    = 'VOID',
   DEFAULT    = .TRUE.
   THICKNESS  = 0.15 /
&SURF ID        = 'InsideWall',
     MATL_ID    = 'CONCRETE',
     COLOR      = 'SILVER',
     BACKING    = 'EXPOSED',
     THICKNESS  = 0.15 /
&SURF ID='INSULATION_MAT',
      MATL_ID = 'CSB',
      COLOR = 'BLACK' ,
```

BACKING = 'EXPOSED',
THICKNESS = 0.01 /
CALCIUM_SILICATE_BOARD
&MATL ID = 'CSB',
EMISSIVITY = 0.9,
DENSITY = 225.,
CONDUCTIVITY= 0.21,
SPECIFIC_HEAT= 0.84, /

Calculations:

Talon Dimensiot

Leveys	25	Pituus	30.8	korkeus	2.5
Seinän paksuus		0.2			

Rooms	W	L	H	S	
1	10	5	2.5	175	m2
2	10	5	2.5	175	m2
3	10	5	2.5	175	m2
4	10	10	2.5	300	m2
5	10	5	2.5	175	m2
6	10	5	2.5	175	m2
7	10	5	2.5	175	m2
8	10	10	2.5	300	m2
9	10	5	2.5	175	m2
10	10	5	2.5	175	m2
11	4.6	5	2.5	94	m2

Leakeage are calculation — This area will be evenly split between the door and the window

cd	0.6	rho	1.225	dp	50	q50	1.5	m3/m2/h
Room	Q m3/s	S m2					0.000416667	m3/m2/s
1	0.072916667	0.01345066						
2	0.072916667	0.01345066						
3	0.072916667	0.01345066						
4	0.125	0.023058275						
5	0.072916667	0.01345066						
6	0.072916667	0.01345066						
7	0.072916667	0.01345066						
8	0.125	0.023058275						
9	0.072916667	0.01345066						
10	0.072916667	0.01345066						
11	0.039166667	0.007224926						

Geometry:

&OBST	XB=	0	0	0	30.8	0	2.5	SURF_ID="OuterWall"/	0	m2	
&OBST	XB=	25	25	0	30.8	0	2.5	SURF_ID="OuterWall"/			
&OBST	XB=	0	25	0	0	0	2.5	SURF_ID="OuterWall"/	0	m2	
&OBST	XB=	0	25	30.8	31	0	2.5	SURF_ID="OuterWall"/			
Huoneeiden seinät leveyssuunnassa						Ensimmäinen sivu					
&OBST	XB=	0	10	5	5.2	0	2.5	SURF_ID="ApartmentWall"/	50	m2	
&OBST	XB=	0	10	10.2	10.4	0	2.5	SURF_ID="ApartmentWall"/	50	m2	
&OBST	XB=	0	10	15.4	15.6	0	2.5	SURF_ID="ApartmentWall"/	50	m2	
&OBST	XB=	0	10	25.6	25.8	0	2.5	SURF_ID="ApartmentWall"/	100	m2	
Huoneiden seinät leveyssuunnassa						Toinen sivu					
&OBST	XB=	15	25	5	5.2	0	2.5	SURF_ID="ApartmentWall"/	50	m2	
&OBST	XB=	15	25	10.2	10.4	0	2.5	SURF_ID="ApartmentWall"/	50	m2	
&OBST	XB=	15	25	15.4	15.6	0	2.5	SURF_ID="ApartmentWall"/	50	m2	
&OBST	XB=	15	25	25.6	25.8	0	2.5	SURF_ID="ApartmentWall"/	100	m2	
Väliseinät							W	L	A=		
&OBST	XB=	10	10.2	25.8	30.8	0	2.5	SURF_ID="ApartmentWall"/	50	5	
	250										
&OBST	XB=	14.8	15	25.8	30.8	0	2.5	SURF_ID="ApartmentWall"/	50	5	
	250										
&OBST	XB=	10.2	14.8	25.6	25.8	0	2.5	SURF_ID="ApartmentWall"/	0.92	5	4.6
Käytävän seinät											
&OBST	XB=	10	10.2	0.2	25.8	0	2.5	SURF_ID="ApartmentWall"/			
&OBST	XB=	14.8	15	0.2	25.8	0	2.5	SURF_ID="ApartmentWall"/			
Kevyet väliseinät huoneessa											
&OBST	XB=	4	10	3	3	0	2.5	SURF_ID="InsideWall"/			
&OBST	XB=	4	4	0	3	0	2.5	SURF_ID="InsideWall"/			
&OBST	XB=	8	8	0	3	0	2.5	SURF_ID="InsideWall"/			
Ovet											
&HOLE	XB=	6.8	7.8	2.9	3.1	0	2	/	Makuuhuone		
&HOLE	XB=	8.5	9.5	2.9	3.1	0	2	/	Kylppäri		

Fire Vent:

Tulipalo makuuhuoneessa

&VENT	XB=	4.0	6.5	0.5	1.5	0	0	SURF_ID=	'fire1'	IOR=	3
COLOR=	'RED' / A fuel area of 3 m2 is required.										

Pressure Zones:

		Zonet:	Huoneet					
&ZONE	XB=	0	10	0	5	0	2.5	/
&ZONE	XB=	0	10	5.2	10.2	0	2.5	/
&ZONE	XB=	0	10	10.4	15.4	0	2.5	/
&ZONE	XB=	0	10	15.6	25.6	0	2.5	/
&ZONE	XB=	15	25	0	5	0	2.5	/
&ZONE	XB=	15	25	5.2	10.2	0	2.5	/
&ZONE	XB=	15	25	10.4	15.4	0	2.5	/
&ZONE	XB=	15	25	15.6	25.6	0	2.5	/
&ZONE	XB=	0	10	25.8	30.8	0	2.5	/
&ZONE	XB=	10.2	14.8	25.8	30.8	0	2.5	/
&ZONE	XB=	15	25	25.8	30.8	0	2.5	/
&ZONE	XB=	10.2	14.8	0	25.6	0	2.5	/

Meshes:

&MESH	XB=	0	10	0	5	0	2.5	IJK=	100	50	25
						/	Fire mesh				
&MESH	XB=	0	10	5.2	10.2	0	2.5	IJK=	20	10	5
					/						
&MESH	XB=	0	10	10.4	15.4	0	2.5	IJK=	20	10	5
				/							
&MESH	XB=	0	10	15.6	25.6	0	2.5	IJK=	20	20	5
				/							
&MESH	XB=	15	25	0	5	0	2.5	IJK=	20	10	5
						/					
&MESH	XB=	15	25	5.2	10.2	0	2.5	IJK=	20	10	5
					/						
&MESH	XB=	15	25	10.4	15.4	0	2.5	IJK=	20	10	5
				/							
&MESH	XB=	15	25	15.6	25.6	0	2.5	IJK=	20	20	5
				/				51.6			
&MESH	XB=	0	10	25.8	30.8	0	2.5	IJK=	20	10	5
				/							
&MESH	XB=	10.2	14.8	25.8	30.8	0	2.5	IJK=	9	10	5
		/									
&MESH	XB=	15	25	25.8	30.8	0	2.5	IJK=	20	10	5
				/							
&MESH	XB=	10.2	14.8	0	25.6	0	2.5	IJK=	9	51	5
			/								

Local Leak Vents:

Huoneistokohtaiset vuodot: Ikkunat, local leak							Ensimmäinen sivu	
		C						
&VENT	XB=	0	0	1.4	3.4	0.5	2	SURF_ID='Ikkuna', ID='Ikkuna 1'/
	2.4		1					
&VENT	XB=	0	0	6.2	9.2	0.5	2	SURF_ID='Ikkuna', ID='Ikkuna 2'/
	7.7	#REF!	2					
&VENT	XB=	0	0	11.4	14.4	0.5	2	SURF_ID='Ikkuna', ID='Ikkuna 3'/
	12.9		3					
&VENT	XB=	0	0	18.1	23.1	0.5	2	SURF_ID='Ikkuna', ID='Ikkuna 4'/
	20.6		4					
Huoneistokohtaiset vuodot: Ikkunat, local leak							Toinen sivu	
	C							
&VENT	XB=	25	25	1.4	3.4	0.5	2	SURF_ID='Ikkuna', ID='Ikkuna 5'/
	2.4		5					
&VENT	XB=	25	25	6.2	9.2	0.5	2	SURF_ID='Ikkuna', ID='Ikkuna 6'/
	7.7		6					
&VENT	XB=	25	25	11.4	14.4	0.5	2	SURF_ID='Ikkuna', ID='Ikkuna 7'/
	12.9	W	7					
&VENT	XB=	25	25	18.1	23.1	0.5	2	SURF_ID='Ikkuna', ID='Ikkuna 8'/
	20.6	2	8					
		3						
Huoneistokohtaiset vuodot: Ovet, local leak							Ensimmäinen sivu	
		C	3					
&VENT	XB=	10	10	3.8	4.8	0	2	SURF_ID='Ovi', ID='Ovi 1 Huone'/
	2.4	5	9					
&VENT	XB=	10	10	7.2	8.2	0	2	SURF_ID='Ovi', ID='Ovi 2 Huone'/
	7.7		10					
&VENT	XB=	10	10	12.4	13.4	0	2	SURF_ID='Ovi', ID='Ovi 3 Huone'/
	12.9	W	11					

&VENT XB= 10 10 20.1 21.1 0 2 SURF_ID='Ovi', ID='Ovi 4 Huone'/
20.6 2 12
Käytävän puolen ovet 3
&VENT XB= 10.2 10.2 3.8 4.8 0 2 SURF_ID='Ovi', ID='Ovi 1 Käytävä'/
3 12
&VENT XB= 10.2 10.2 7.2 8.2 0 2 SURF_ID='Ovi', ID='Ovi 2 Käytävä'/
5 13
&VENT XB= 10.2 10.2 12.4 13.4 0 2 SURF_ID='Ovi', ID='Ovi 3 Käytävä'/
14
&VENT XB= 10.2 10.2 20.1 21.1 0 2 SURF_ID='Ovi', ID='Ovi 4 Käytävä'/
15
1
Huoneistokohtaiset vuodot: Ovet, local leak Toinen sivu
C 1
&VENT XB= 15 15 1.9 2.9 0 2 SURF_ID='Ovi', ID='Ovi 5 Huone'/
2.4 1 16
&VENT XB= 15 15 7.2 8.2 0 2 SURF_ID='Ovi', ID='Ovi 6 Huone'/
7.7 1 17
&VENT XB= 15 15 12.4 13.4 0 2 SURF_ID='Ovi', ID='Ovi 7 Huone'/
12.9 18
&VENT XB= 15 15 20.1 21.1 0 2 SURF_ID='Ovi', ID='Ovi 8 Huone'/
20.6 19
Käytävän puolen ovet
&VENT XB= 14.8 14.8 1.9 2.9 0 2 SURF_ID='Ovi', ID='Ovi 5 Käytävä'/
19
&VENT XB= 14.8 14.8 7.2 8.2 0 2 SURF_ID='Ovi', ID='Ovi 6 Käytävä'/
20
&VENT XB= 14.8 14.8 12.4 13.4 0 2 SURF_ID='Ovi', ID='Ovi 7 Käytävä'/
21
&VENT XB= 14.8 14.8 20.1 21.1 0 2 SURF_ID='Ovi', ID='Ovi 8 Käytävä'/
22
1
Huoneistokohtaiset vuodot: Ikkunat, local leak Päätyhuoneistot
1
&VENT XB= 0 0 27.3 29.3 0.5 2 SURF_ID='Ikkuna', ID='Ikkuna 9'/
1 23
&VENT XB= 25 25 27.3 29.3 0.5 2 SURF_ID='Ikkuna', ID='Ikkuna 10'/
1 24
&VENT XB= 11.5 13.5 30.8 30.8 0.5 2 SURF_ID='Ikkuna', ID='Ikkuna 11'/
25
Huoneistokohtaiset vuodot: Ovet, local leak Päätyhuoneistot
&VENT XB= 9.9 8.9 25.8 25.8 0 2 SURF_ID='Ovi', ID='Ovi 9 Huone'/
&VENT XB= 12 13 25.8 25.8 0 2 SURF_ID='Ovi', ID='Ovi 10 Huone'/
&VENT XB= 15.1 16.1 25.8 25.8 0 2 SURF_ID='Ovi', ID='Ovi 11 Huone'/
Käytävän puolen ovet
&VENT XB= 10.7 11.7 25.6 25.6 0 2 SURF_ID='Ovi', ID='Ovi 9 Käytävä'/
&VENT XB= 12 13 25.6 25.6 0 2 SURF_ID='Ovi', ID='Ovi 10 Käytävä'/
&VENT XB= 13.2 14.2 25.6 25.6 0 2 SURF_ID='Ovi', ID='Ovi 11 Käytävä'/

HVACS for LEAKS
Doors
&HVAC ID = 'DOOR1' TYPE_ID = 'LEAK' VENT_ID = 'Ovi 1 Huone' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'DOOR2' TYPE_ID = 'LEAK' VENT_ID = ' Ovi 2 Huone' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'DOOR3' TYPE_ID = 'LEAK' VENT_ID = 'Ovi 3 Huone' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'DOOR4' TYPE_ID = 'LEAK' VENT_ID = 'Ovi 4 Huone' VENT2_ID= 'AMBIENT' AREA= 0.005764569 /
&HVAC ID = 'DOOR5' TYPE_ID = 'LEAK' VENT_ID = 'Ovi 5 Huone' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'DOOR6' TYPE_ID = 'LEAK' VENT_ID = ' Ovi 6 Huone' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'DOOR7' TYPE_ID = 'LEAK' VENT_ID = 'Ovi 7 Huone' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'DOOR8' TYPE_ID = 'LEAK' VENT_ID = 'Ovi 8 Huone' VENT2_ID= 'AMBIENT' AREA= 0.005764569 /
&HVAC ID = 'DOOR9' TYPE_ID = 'LEAK' VENT_ID = ' Ovi 9 Huone' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'DOOR10' TYPE_ID = 'LEAK' VENT_ID = 'Ovi 10 Huone' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'DOOR11' TYPE_ID = 'LEAK' VENT_ID = 'Ovi 11 Huone' VENT2_ID= 'AMBIENT' AREA= 0.001806232 /
Windows
&HVAC ID = 'WINDOW1' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 1' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'WINDOW2' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 2' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'WINDOW3' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 3' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'WINDOW4' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 4' VENT2_ID= 'AMBIENT' AREA= 0.005764569 /
&HVAC ID = 'WINDOW5' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 5' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'WINDOW6' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 6' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'WINDOW7' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 7' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'WINDOW8' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 8' VENT2_ID= 'AMBIENT' AREA= 0.005764569 /
&HVAC ID = 'WINDOW9' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 9' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'WINDOW10' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 10' VENT2_ID= 'AMBIENT' AREA= 0.003362665 /
&HVAC ID = 'WINDOW11' TYPE_ID = 'LEAK' VENT_ID = 'Ikkuna 11' VENT2_ID= 'AMBIENT' AREA= 0.001806232 /

Ventilation system

Inlet and exhaust ducts with 5 nodes 1 outside 4 tees for apartments

----

Inlet nodes

&HVAC TYPE_ID= 'NODE' ID = 'Inlet' XYZ= 12.5 0 2.5 AMBIENT=.TRUE. DUCT_ID= 'Inlet duct 0' /

&HVAC TYPE_ID= 'NODE' ID = 'Node 1' XYZ= 12.5 2.5 2.4 DUCT_ID= 'Inlet duct 0', 'Inlet duct 1'/

&HVAC TYPE_ID= 'NODE' ID = 'Node 2' XYZ= 12.5 2.5 2.4 DUCT_ID= 'Inlet duct 1', 'Inlet duct 2','Inlet duct asunto 1','Inlet duct asunto 5'/

&HVAC TYPE_ID= 'NODE' ID = 'Node 3' XYZ= 12.5 7.7 2.4 DUCT_ID= 'Inlet duct 2', 'Inlet duct 3','Inlet duct asunto 2','Inlet duct asunto 6'/

&HVAC TYPE_ID= 'NODE' ID = 'Node 4' XYZ= 12.5 12.9 2.4 DUCT_ID= 'Inlet duct 3', 'Inlet duct 4','Inlet duct asunto 3','Inlet duct asunto 7' /

&HVAC TYPE_ID= 'NODE' ID = 'Node 5' XYZ= 12.5 20.6 2.4 DUCT_ID= 'Inlet duct 4','Inlet duct asunto 4','Inlet duct asunto 8','Inlet duct asunto 9','Inlet duct asunto 10','Inlet duct asunto 11' /

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 1 jako' XYZ= 10 4.3 2.4 DUCT_ID= 'Inlet duct asunto 1','asunto 1 mhduct','asunto 1 ohduct'/

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 2 in node' XYZ= 10 7.7 2.4 DUCT_ID= 'Inlet duct asunto 2' VENT_ID='Asunto 2 inlet', LOSS = 0,0 /

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 3 in node' XYZ= 10 12.9 2.4 DUCT_ID= 'Inlet duct asunto 3' VENT_ID='Asunto 3 inlet', LOSS = 0,0 /

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 4 in node' XYZ= 10 20.6 2.4 DUCT_ID= 'Inlet duct asunto 4' VENT_ID='Asunto 4 inlet', LOSS = 0,0 /

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 5 in node' XYZ= 15 2.4 2.4 DUCT_ID= 'Inlet duct asunto 5' VENT_ID='Asunto 5 inlet', LOSS = 0,0 /

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 6 in node' XYZ= 10.2 7.7 2.4 DUCT_ID= 'Inlet duct asunto 6' VENT_ID='Asunto 6 inlet', LOSS = 0,0 /

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 7 in node' XYZ= 10.2 12.9 2.4 DUCT_ID= 'Inlet duct asunto 7' VENT_ID='Asunto 7 inlet', LOSS = 0,0 /

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 8 in node' XYZ= 10.2 20.6 2.4 DUCT_ID= 'Inlet duct asunto 8' VENT_ID='Asunto 8 inlet', LOSS = 0,0 /

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 9 in node' XYZ= 5 28.3 2.4 DUCT_ID= 'Inlet duct asunto 9' VENT_ID='Asunto 9 inlet' LOSS = 0,0 /

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 10 in node' XYZ= 12.5 28.3 2.4 DUCT_ID='Inlet duct asunto 10' VENT_ID='Asunto 10 inlet' LOSS = 0,0 /

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 11 in node' XYZ= 20 28.3 2.4 DUCT_ID= 'Inlet duct asunto 11' VENT_ID='Asunto 11 inlet' LOSS = 0,0 /

More detail for fire apartemnt

&HVAC TYPE_ID= 'NODE' ID= 'Asunto makuuhuone in node' XYZ= 7.3 3 2.4 DUCT_ID= 'asunto 1 mhduct' VENT_ID='Asunto 1 inlet mh' LOSS = 0,0/

&HVAC TYPE_ID= 'NODE' ID= 'Asunto olohuone in node' XYZ= 7.3 3 2.4 DUCT_ID= 'asunto 1 ohduct' VENT_ID='Asunto 1 inlet oh' LOSS = 0,0/

Inlet Ducts

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct 0' NODE_ID= 'Inlet' 'Node 1' LENGTH= 1 AREA= 0.049087385 ROUGHNESS=0.001 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct 1' NODE_ID= 'Node 1', 'Node 2' LENGTH= 2.5 AREA= 0.049087385 ROUGHNESS=0.001, LOSS=2,2 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct 2' NODE_ID= 'Node 2' 'Node 3' LENGTH= 5.2 AREA= 0.049087385 ROUGHNESS=0.001, LOSS=0,0 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct 3' NODE_ID= 'Node 3' 'Node 4' LENGTH= 5.2 AREA= 0.049087385 ROUGHNESS=0.001, LOSS=0,0 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct 4' NODE_ID= 'Node 4' 'Node 5' LENGTH= 7.7 AREA= 0.049087385 ROUGHNESS=0.001, LOSS=0,0 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 1' NODE_ID= 'Node 2' 'Asunto 1 jako' LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=14,14 DAMPER=.TRUE., DEVC_ID='TIMER'/

&DEVC QUANTITY='TIME',ID='TIMER',SETPOINT=10,INITIAL_STATE=.TRUE.,XYZ=10,4.3,2.4/

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 2' NODE_ID= 'Node 3' 'Asunto 2 in node' LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=11,11 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 3' NODE_ID= 'Node 4', 'Asunto 3 in node' , LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=9,9 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 4' NODE_ID= 'Node 5' 'Asunto 4 in node' LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=5,5 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 5' NODE_ID= 'Node 2' 'Asunto 5 in node' LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=14,14 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 6' NODE_ID= 'Node 3' 'Asunto 6 in node' LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=11,11 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 7' NODE_ID= 'Node 4' 'Asunto 7 in node' LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=9,9 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 8' NODE_ID= 'Node 5' 'Asunto 8 in node' LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=5,5 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 9' NODE_ID= 'Node 5' 'Asunto 9 in node' LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=7,7 /

&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 10' NODE_ID= 'Node 5' 'Asunto 10 in node' LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=7,7 /

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&HVAC TYPE_ID= 'DUCT' ID= 'Inlet duct asunto 11' NODE_ID= 'Node 5' 'Asunto 11 in node'
LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001, LOSS=7,7/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 1' NODE_ID= 'ENode 2' 'Asunto 1 ex jako'
LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001,LOSS=7,7 ,DAMPER=.TRUE., DEVC_ID='TIMER'/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 2' NODE_ID= 'ENode 3' 'Asunto 2 ex node'
LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001,LOSS=7,7/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 3' NODE_ID= 'ENode 4', 'Asunto 3 ex node' ,
LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001,LOSS=7,7/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 4' NODE_ID= 'ENode 5' 'Asunto 4 ex node'
LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001,LOSS=5,5/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 5' NODE_ID= 'ENode 2' 'Asunto 5 ex node'
LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001,LOSS=7,7/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 6' NODE_ID= 'ENode 3' 'Asunto 6 ex node'
LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001,LOSS=7,7/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 7' NODE_ID= 'ENode 4' 'Asunto 7 ex node'
LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001,LOSS=7,7/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 8' NODE_ID= 'ENode 5' 'Asunto 8 ex node'
LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001,LOSS=5,5/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 9' NODE_ID= 'ENode 5' 'Asunto 9 ex node'
LENGTH= 2 AREA= 0.01227 ROUGHNESS=0.001,LOSS=7,7/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 10' NODE_ID= 'ENode 5' 'Asunto 10 ex node' LENGTH= 2
AREA= 0.01227 ROUGHNESS=0.001,LOSS=7,7/
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct asunto 11' NODE_ID= 'ENode 5' 'Asunto 11 ex node' LENGTH= 2
AREA= 0.01227 ROUGHNESS=0.001,LOSS=7,7/
&HVAC TYPE_ID= 'DUCT' ID= 'asunto 1 kphduct' NODE_ID= 'Asunto 1 ex jako' 'Asunto kph ex node' LENGTH= 3
AREA= 0.01227 /
&HVAC TYPE_ID= 'DUCT' ID= 'asunto 1 kduct' NODE_ID= 'Asunto 1 ex jako' 'Asunto k ex node' LENGTH= 1 AREA=
0.01227 /
&HVAC TYPE_ID= 'DUCT' ID= 'asunto 1 mhduct' NODE_ID= 'Asunto 1 jako' 'Asunto makuuhuone in node'
LENGTH= 3 AREA= 0.01227 /
&HVAC TYPE_ID= 'DUCT' ID= 'asunto 1 ohduct' NODE_ID= 'Asunto 1 jako' 'Asunto olohuone in node' LENGTH= 1
AREA= 0.01227 /
&VENT ID= 'Asunto 1 inlet mh' SURF_ID= 'HVAC' XB= 7.0 7.5 0 0 2.0 2.5
COLOR = "GREEN" /
&VENT ID= 'Asunto 1 inlet oh' SURF_ID= 'HVAC' XB= 10 10 4.0 4.5 2.0 2.5
COLOR = "GREEN" /
&VENT ID= 'Asunto 2 inlet' SURF_ID= 'HVAC' XB= 10 10 9.0 9.5 2.0 2.5
COLOR = "GREEN" /
&VENT ID= 'Asunto 3 inlet' SURF_ID= 'HVAC' XB= 10 10 14.0 14.5 2.0 2.5
COLOR = "GREEN" /
&VENT ID= 'Asunto 4 inlet' SURF_ID= 'HVAC' XB= 10 10 19.0 19.5 2.0 2.5
COLOR = "GREEN" /
&VENT ID= 'Asunto 5 inlet' SURF_ID= 'HVAC' XB= 15 15 4.0 4.5 2.0 2.5
COLOR = "GREEN" /
&VENT ID= 'Asunto 6 inlet' SURF_ID= 'HVAC' XB= 15 15 9.0 9.5 2.0 2.5
COLOR = "GREEN" /
&VENT ID= 'Asunto 7 inlet' SURF_ID= 'HVAC' XB= 15 15 14.0 14.5 2.0 2.5
COLOR = "GREEN" /
&VENT ID= 'Asunto 8 inlet' SURF_ID= 'HVAC' XB= 15 15 19.0 19.5 2.0 2.5
COLOR = "GREEN" /
&VENT ID= 'Asunto 9 inlet' SURF_ID= 'HVAC' XB= 10 10 29 30 2.0 2.5 COLOR = "GREEN"/
&VENT ID= 'Asunto 10 inlet' SURF_ID= 'HVAC' XB= 14.8 14.8 29 30 2.0 2.5 COLOR = "GREEN" /
&VENT ID= 'Asunto 11 inlet' SURF_ID= 'HVAC' XB= 25 25 29 30 2.0 2.5 COLOR = "GREEN" /
-----------------------------------------------------------------------------------------------------------------------
Exhaust
Exhaust nodes
&HVAC TYPE_ID= 'NODE' ID = 'Exhaust' XYZ= 12.5 0 2.5 AMBIENT=.TRUE. DUCT_ID=
'Exhaust duct 0' /
&HVAC TYPE_ID= 'NODE' ID = 'ENode 1' XYZ= 12.5 2.5 2.4 DUCT_ID= 'Exhaust duct 0', 'Exhaust duct 1'/
&HVAC TYPE_ID= 'NODE' ID = 'ENode 2' XYZ= 12.5 2.5 2.4 DUCT_ID= 'Exhaust duct 1', 'Exhaust duct
2','Exhaust duct asunto 1','Exhaust duct asunto 5'/
&HVAC TYPE_ID= 'NODE' ID = 'ENode 3' XYZ= 12.5 7.7 2.4 DUCT_ID= 'Exhaust duct 2', 'Exhaust duct
3','Exhaust duct asunto 2','Exhaust duct asunto 6'/
&HVAC TYPE_ID= 'NODE' ID = 'ENode 4' XYZ= 12.5 12.9 2.4 DUCT_ID= 'Exhaust duct 3', 'Exhaust duct
4','Exhaust duct asunto 3','Exhaust duct asunto 7' /
&HVAC TYPE_ID= 'NODE' ID = 'ENode 5' XYZ= 12.5 20.6 2.4 DUCT_ID= 'Exhaust duct 4','Exhaust duct asunto
4','Exhaust duct asunto 8','Exhaust duct asunto 9','Exhaust duct asunto 10','Exhaust duct asunto 11' /
&HVAC TYPE_ID= 'NODE' ID= 'Asunto 1 ex jako' XYZ= 10 4.3 2.4 DUCT_ID= 'Exhaust duct asunto
1','asunto 1 kphduct','asunto 1 kduct' /
&HVAC TYPE_ID= 'NODE' ID= 'Asunto 2 ex node' XYZ= 10 7.7 2.4 DUCT_ID= 'Exhaust duct asunto
2' VENT_ID='Asunto 2 Exhaust' LOSS = 0,0/
&HVAC TYPE_ID= 'NODE' ID= 'Asunto 3 ex node' XYZ= 10 12.9 2.4 DUCT_ID= 'Exhaust duct asunto
3' VENT_ID='Asunto 3 Exhaust' LOSS = 0,0/
&HVAC TYPE_ID= 'NODE' ID= 'Asunto 4 ex node' XYZ= 10 20.6 2.4 DUCT_ID= 'Exhaust duct asunto
4' VENT_ID='Asunto 4 Exhaust' LOSS = 0,0/
```

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&HVAC TYPE_ID= 'NODE' ID= 'Asunto 5 ex node' XYZ= 15 2.4 2.4 DUCT_ID= 'Exhaust duct asunto
5' VENT_ID='Asunto 5 Exhaust' LOSS = 0,0 /
&HVAC TYPE_ID= 'NODE' ID= 'Asunto 6 ex node' XYZ= 10.2 7.7 2.4 DUCT_ID= 'Exhaust duct asunto
6' VENT_ID='Asunto 6 Exhaust' LOSS = 0,0/
&HVAC TYPE_ID= 'NODE' ID= 'Asunto 7 ex node' XYZ= 10.2 12.9 2.4 DUCT_ID= 'Exhaust duct asunto
7' VENT_ID='Asunto 7 Exhaust' LOSS = 0,0/
&HVAC TYPE_ID= 'NODE' ID= 'Asunto 8 ex node' XYZ= 10.2 20.6 2.4 DUCT_ID= 'Exhaust duct asunto
8' VENT_ID='Asunto 8 Exhaust' LOSS = 0,0/

&HVAC TYPE_ID= 'NODE' ID= 'Asunto 9 ex node' XYZ= 5 28.3 2.4 DUCT_ID= 'Exhaust duct asunto
9' VENT_ID='Asunto 9 Exhaust' LOSS = 0,0 /
&HVAC TYPE_ID= 'NODE' ID= 'Asunto 10 ex node' XYZ= 12.5 28.3 2.4 DUCT_ID= 'Exhaust duct asunto
10' VENT_ID='Asunto 10 Exhaust' LOSS = 0,0 /
&HVAC TYPE_ID= 'NODE' ID= 'Asunto 11 ex node' XYZ= 20 28.3 2.4 DUCT_ID= 'Exhaust duct asunto
11' VENT_ID='Asunto 11 Exhaust' LOSS = 0,0/
More detail for fire apartemnt
&HVAC TYPE_ID= 'NODE' ID= 'Asunto k ex node' XYZ= 7.3 3 2.4 DUCT_ID= 'asunto 1 kduct'
VENT_ID='Asunto 1 Exhaust k' LOSS = 0,0/
&HVAC TYPE_ID= 'NODE' ID= 'Asunto kph ex node' XYZ= 7.3 3 2.4 DUCT_ID= 'asunto 1 kphduct'
VENT_ID='Asunto 1 Exhaust kph' LOSS=10,0/
Exhaust Ducts
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct 0' NODE_ID= 'Exhaust' 'ENode 1' LENGTH= 1
AREA= 0.049087385 /
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct 1' NODE_ID= 'ENode 1' 'ENode 2' LENGTH=
2.5,ROUGHNESS=0.001, AREA= 0.049087385,LOSS=2,2 /
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct 2' NODE_ID= 'ENode 2' 'ENode 3' LENGTH=
5.2,ROUGHNESS=0.001, AREA= 0.049087385 /
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct 3' NODE_ID= 'ENode 3' 'ENode 4' LENGTH=
5.2,ROUGHNESS=0.001, AREA= 0.049087385 /
&HVAC TYPE_ID= 'DUCT' ID= 'Exhaust duct 4' NODE_ID= 'ENode 4' 'ENode 5' LENGTH=
7.7,ROUGHNESS=0.001, AREA= 0.049087385 /
&VENT COLOR="BLUE" ID= 'Asunto 1 Exhaust kph' SURF_ID= 'HVAC' XB= 8.5 9.5 0 0 2.0
2.5 /
&VENT COLOR="BLUE" ID= 'Asunto 1 Exhaust k' SURF_ID= 'HVAC' XB= 1.0 1.5 0 0 2.0
2.5 /
&VENT COLOR="BLUE" ID= 'Asunto 2 Exhaust' SURF_ID= 'HVAC' XB= 0 0 9.0 9.5 2.0
2.5 /
&VENT COLOR="BLUE" ID= 'Asunto 3 Exhaust' SURF_ID= 'HVAC' XB= 0 0 14.0 14.5 2.0
2.5 /
&VENT COLOR="BLUE" ID= 'Asunto 4 Exhaust' SURF_ID= 'HVAC' XB= 0 0 19.0 19.5 2.0
2.5 /
&VENT COLOR="BLUE" ID= 'Asunto 5 Exhaust' SURF_ID= 'HVAC' XB= 25 25 4.0 4.5 2.0
2.5 /
&VENT COLOR="BLUE" ID= 'Asunto 6 Exhaust' SURF_ID= 'HVAC' XB= 25 25 9.0 9.5 2.0
2.5 /
&VENT COLOR="BLUE" ID= 'Asunto 7 Exhaust' SURF_ID= 'HVAC' XB= 25 25 14.0 14.5 2.0
2.5 /
&VENT COLOR="BLUE" ID= 'Asunto 8 Exhaust' SURF_ID= 'HVAC' XB= 25 25 19.0 19.5 2.0
2.5 /
&VENT COLOR="BLUE" ID= 'Asunto 9 Exhaust' SURF_ID= 'HVAC' XB= 0 0 29 30 2.0 2.5/
&VENT COLOR="BLUE" ID= 'Asunto 10 Exhaust' SURF_ID= 'HVAC' XB= 10.2 10.2 29 30 2.0 2.5 /
&VENT COLOR="BLUE" ID= 'Asunto 11 Exhaust' SURF_ID= 'HVAC' XB= 15 15 29 30 2.0 2.5 /
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Devices:
&DEVC ID='PRES1', QUANTITY='PRESSURE', XYZ = 2.5, 2.4,2.4/
&DEVC ID='PRES2', QUANTITY='PRESSURE', XYZ = 2.5, 7.4,2.4/
&DEVC ID='PRES3', QUANTITY='PRESSURE', XYZ = 2.5, 12.4,2.4/
&DEVC ID='PRES4', QUANTITY='PRESSURE', XYZ = 2.5, 22.4,2.4/
&DEVC ID='PRES5', QUANTITY='PRESSURE', XYZ = 17.5, 2.4,2.4/
&DEVC ID='PRES6', QUANTITY='PRESSURE', XYZ = 17.5, 7.0,2.4/
&DEVC ID='PRES7', QUANTITY='PRESSURE', XYZ = 17.5, 12.0,2.4/
&DEVC ID='PRES8', QUANTITY='PRESSURE', XYZ = 17.5, 22.4,2.0/
&DEVC ID='PRES9', QUANTITY='PRESSURE', XYZ = 0.5, 29.5,2.4/
&DEVC ID='PRES10', QUANTITY='PRESSURE', XYZ = 10.5, 29.5,2.4/
&DEVC ID='PRES11', QUANTITY='PRESSURE', XYZ = 15.5, 29.5,2.4/
&DEVC ID='VIS1', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 2.5, 2.4,2.4/
&DEVC ID='VIS2', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 2.5, 7.4,2.4/
&DEVC ID='VIS3', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 2.5, 12.4,2.4/
&DEVC ID='VIS4', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 2.5, 22.4,2.4/
&DEVC ID='VIS5', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 17.5, 2.4,2.4/
&DEVC ID='VIS6', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 17.5, 7.0,2.4/
&DEVC ID='VIS7', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 17.5, 12.0,2.4/
&DEVC ID='VIS8', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 17.5, 22.4,2.0/
&DEVC ID='VIS9', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 0.5, 29.5,2.4/
&DEVC ID='VIS10', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 10.5, 29.5,2.4/
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&DEVC ID='VIS11', QUANTITY='VISIBILITY', STATISTICS='MIN',XYZ = 15.5, 29.5,2.4/
&DEVC    ID="SOOTF1",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    0    10    0    5    0
         2.5    /
&DEVC    ID="SOOTF2",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    0    10    5.2    10.2    0
         2.5    /
&DEVC    ID="SOOTF3",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    0    10    10.4    15.4    0
         2.5    /
&DEVC    ID="SOOTF4",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    0    10    15.6    25.6    0
         2.5    /
&DEVC    ID="SOOTF5",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    15    25    0    5    0
         2.5    /
&DEVC    ID="SOOTF6",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    15    25    5.2    10.2    0
         2.5    /
&DEVC    ID="SOOTF7",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    15    25    10.4    15.4    0
         2.5    /
&DEVC    ID="SOOTF8",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    15    25    15.6    25.6    0
         2.5    /

&DEVC    ID="SOOTF9",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    0    10    25.8    30.8    0
         2.5    /
&DEVC    ID="SOOTF10",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    10.2    14.8    25.8    30.8    0
         2.5    /
&DEVC    ID="SOOTF11",STATISTICS="MEAN",QUANTITY="VOLUME FRACTION",SPEC_ID="SOOT",XB=    15    25    25.8    30.8    0
         2.5    /
&DEVC ID='TotalInletVolFlow', QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct 1' /
&DEVC ID='Asunto1VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 1' /
&DEVC ID='TotalExhaustVolFlow', QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct 1' /
&DEVC ID='Asunto1EVolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 1' /
&DEVC ID='Educt2VolFlow', QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct 2' /
&DEVC ID='Educt3VolFlow', QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct 3' /
&DEVC ID='Educt4VolFlow', QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct 4' /
&DEVC ID='Asunto2VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 2' /
&DEVC ID='Asunto3VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 3' /
&DEVC ID='Asunto4VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 4' /
&DEVC ID='Asunto5VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 5' /
&DEVC ID='Asunto6VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 6' /
&DEVC ID='Asunto7VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 7' /
&DEVC ID='Asunto8VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 8' /
&DEVC ID='Asunto9VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 9' /
&DEVC ID='Asunto10VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 10' /
&DEVC ID='Asunto11VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Inlet duct asunto 11' /
&DEVC ID='Asunto2InSoot' ,NODE_ID='Asunto 2 in node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto3InSoot' ,NODE_ID='Asunto 3 in node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto4InSoot' ,NODE_ID='Asunto 4 in node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto5InSoot' ,NODE_ID='Asunto 5 in node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto6InSoot' ,NODE_ID='Asunto 6 in node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto7InSoot' ,NODE_ID='Asunto 7 in node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto8InSoot' ,NODE_ID='Asunto 8 in node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto9InSoot' ,NODE_ID='Asunto 9 in node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto10InSoot' ,NODE_ID='Asunto 10 in node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT' /
&DEVC ID='Asunto11InSoot' ,NODE_ID='Asunto 11 in node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT' /
&DEVC ID='Asunto2ExSoot' ,NODE_ID='Asunto 2 ex node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto3ExSoot' ,NODE_ID='Asunto 3 ex node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto4ExSoot' ,NODE_ID='Asunto 4 ex node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto5ExSoot' ,NODE_ID='Asunto 5 ex node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto6ExSoot' ,NODE_ID='Asunto 6 ex node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto7ExSoot' ,NODE_ID='Asunto 7 ex node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto8ExSoot' ,NODE_ID='Asunto 8 ex node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto9ExSoot' ,NODE_ID='Asunto 9 ex node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT'/
&DEVC ID='Asunto10ExSoot' ,NODE_ID='Asunto 10 ex node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT' /
&DEVC ID='Asunto11ExSoot' ,NODE_ID='Asunto 11 ex node'   , QUANTITY='NODE VOLUME FRACTION',SPEC_ID='SOOT' /
&DEVC ID='Asunto2EVolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 2' /
&DEVC ID='Asunto3EVolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 3' /
&DEVC ID='Asunto4EVolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 4' /
&DEVC ID='Asunto5EVolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 5' /
&DEVC ID='Asunto6EVolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 6' /
&DEVC ID='Asunto7EVolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 7' /
&DEVC ID='Asunto8EVolFlow'    , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 8' /
&DEVC ID='Asunto9EVolFlow'    , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 9' /
&DEVC ID='Asunto10EVolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 10' /
&DEVC ID='Asunto11EVolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='Exhaust duct asunto 11' /
&DEVC ID='DOOR1VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR1' /
&DEVC ID='DOOR2VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR2' /
&DEVC ID='DOOR3VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR3' /
&DEVC ID='DOOR4VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR4' /
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&DEVC ID='DOOR5VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR5' /
&DEVC ID='DOOR6VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR6' /
&DEVC ID='DOOR7VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR7' /
&DEVC ID='DOOR8VolFlow'    , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR8' /
&DEVC ID='DOOR9VolFlow'    , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR9' /
&DEVC ID='DOOR10VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR10' /
&DEVC ID='DOOR11VolFlow'   , QUANTITY='DUCT VOLUME FLOW', DUCT_ID='DOOR11' /
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&DEVC ID='DOOR1Temp'   , QUANTITY='DUCT TEMPERATURE', DUCT_ID='DOOR1' /
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&DEVC ID='InletA1MassFlow'   , QUANTITY='DUCT MASS FLOW', DUCT_ID='Inlet duct asunto 1' /
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&DEVC ID='ExhaustA1MassFlow'   , QUANTITY='DUCT MASS FLOW', DUCT_ID='Exhaust duct asunto 1' /
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